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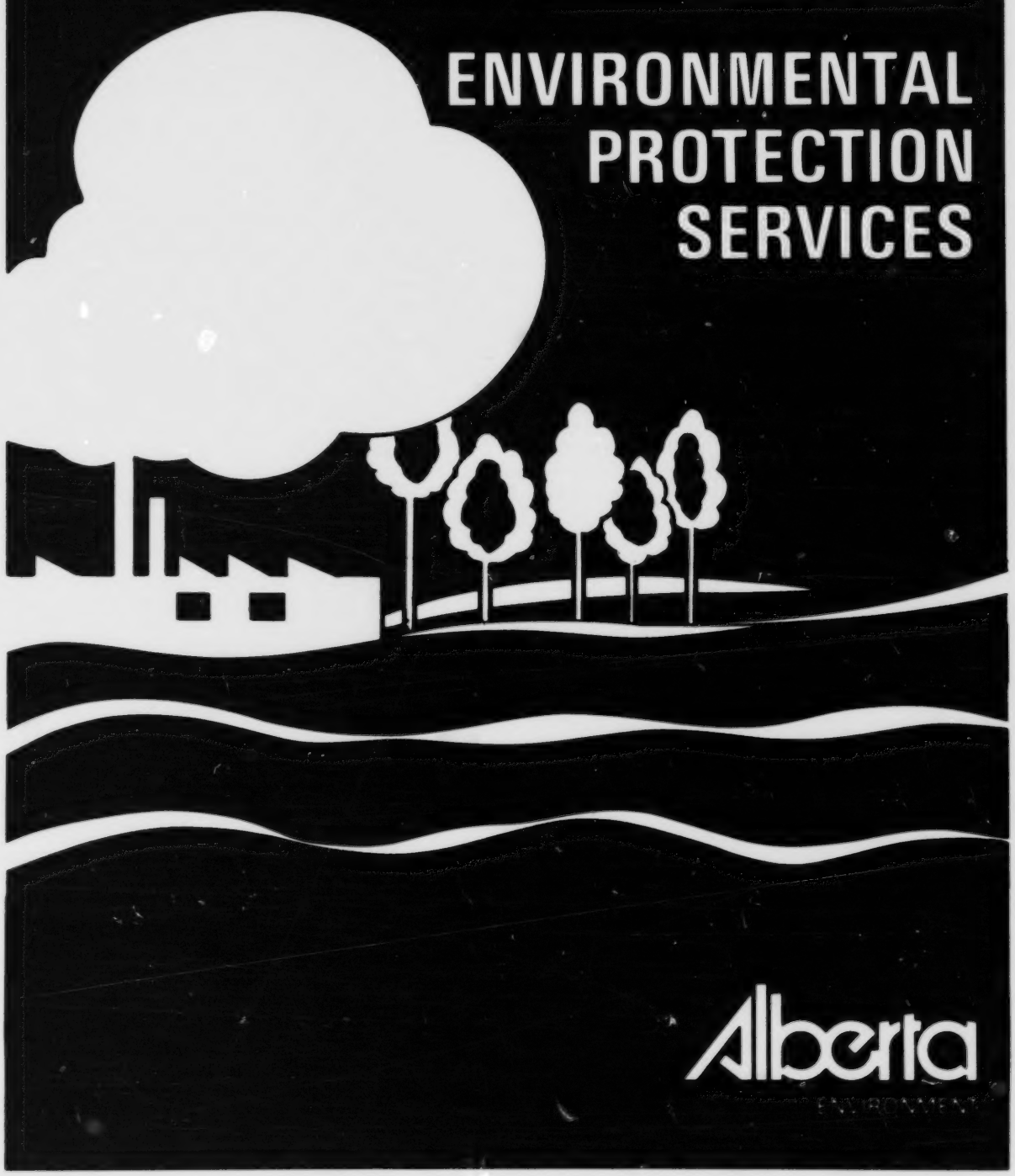
GUIDELINES
for
PLUME DISPERSION
CALCULATIONS

ENVIRONMENTAL PROTECTION SERVICES



Alberta
ENVIRONMENT

GUIDELINES
for
PLUME DISPERSION
CALCULATIONS

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In accordance with Part 1, section 4 of The Clean Air (General) Regulations being Alberta Statute 216/75, the Department of the Environment hereby issues

GUIDELINES

for

PLUME DISPERSION

CALCULATIONS

Standards & Approvals Division

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1. INTRODUCTION

The assimilative capacity of the atmosphere can be regarded as a natural resource which mankind uses for the disposal of unwanted byproducts of his activities. This air resource is the most personal of all resources for each individual spends his entire life immersed in it.

Air pollution adversely affects the quality of life. It endangers our health and comfort. It reduces the productivity of agriculture and threatens the very existence of certain species. It damages materials and causes economic loss. It impairs visibility and degrades the beauty of our natural surroundings. Nor are its effects confined to the immediate vicinity of the polluter. Airmasses know no political boundaries. Pollutants can travel over long distances and cause environmental deterioration in areas remote from the source.

Avoiding the problems of air pollution means recognizing the finiteness of the air resource and managing it wisely for the good of everyone. The future growth of industry and human population will place every increasing demands upon this limited resource. It is incumbent upon responsible citizens, corporations and governments everywhere to ensure that the quantities of pollutants emitted into the atmosphere are kept as small as best practicable technology will allow and that the residual waste is discharged so as not to overtax the air resource.

1.2 HOW HIGH SHOULD A STACK BE BUILT?

It is extremely difficult to provide an entirely satisfactory answer to this question when all aspects of the problem are considered. Most of the time the atmosphere is such that it is fairly easy to keep ground level concentrations well below the ambient air quality objectives. But changeability is probably the best known characteristic of the weather. Wide variations are possible and under some adverse weather conditions, concentrations above the ambient air quality objectives will occur. If such levels have detrimental effects on the environment, then obviously the stack should be tall enough to ensure that the concentrations do not exceed the air quality objectives under those adverse conditions. This sounds simple enough; all that one has to do is determine the "worst case".

Unfortunately, it is not easy to determine what constitutes the "worst case". The relevant atmospheric properties are all stochastic rather than deterministic. Therefore, statements about the behavior of the atmosphere can only be statistical. It is impossible to determine an "absolute worst case" because all cases are possible, although, the more extreme the event, the smaller is its probability (or frequency) of occurrence.

This situation is not new. All human activity involves risks. No individual makes decisions or runs his life on the basis of "absolute worst case". Were that the situation, one could not cross a road for fear of being killed by a passing automobile, but neither could one stay in the house, because it might collapse (Whittaker, 1976). It

is common engineering practice to use statistical criteria for structural design of such things as flood control dams and tall buildings. Return periods for extreme floods and wind loads are used to balance the costs of additional safeguards against the risk that the structure will be subjected to the excessive conditions that will damage or destroy it. The steps are twofold; (1) determining the acceptable risk to society; and (2) obtaining the necessary data from which to estimate the frequency distribution function.

For situations involving human fatality, acceptable risks are fairly well established (Whittaker, 1976). For the exceedance of air quality standards when the ultimate consequences are not really known, the acceptable risk is difficult to establish by non-subjective means. Because no definite criteria are available, stack design has been rather more difficult than structural engineering. Moreover, even if one does somehow get around the problem of defining acceptable risk, the calculation of the expected frequency distribution is far from being a trivial exercise. The behavior of the atmosphere is composed of motions over a wide range of size and time scales. It is complicated further by topographical and geographical features which may exert influences in a number of different ways. Scorer (1974) asserted:

> "It cannot be too much emphasised that the difficulties of applying laws of physics, chemistry, and mechanics do not stem from our ignorance of the laws anything like as much as from the complexities of the situation in which they are to be applied. In scientific principle we know enough to solve problems of this kind with great accuracy. In practice we cannot actually handle the very complicated situation, certainly not in the time available."

What, then are we to do? Scorer (1974) answered:

> "There is a great need for general practitioners operating in society. The best family doctors do not operate by the careful application of scientific principles. They try not to go against such scientificially established conclusions as they know about, but experience and knowledge of their patients individually counts for everything."

Thus, many factors may contribute to decisions regarding the requirements for a stack, including; (a) industrial plant operations, immediate and projected; (b) land use, present and future; (c) population density, present and future; (d) air traffic; (e) aesthetics; (f) other pollutant sources; (g) aims, needs and wishes of the populace. Often knowing what to avoid is the most important consideration of all. Problems usually arise because of peculiar conditions of local weather, topography or other influence.

1.3 THE CONCEPT OF A STANDARD SITE

Experience has shown that even though the dispersion capabilities of the atmosphere vary greatly from site to site and season to season, the differences lie within certain loose bounds. Indeed, inherent in diffusion typing schemes is the assumption that the only differences from site to site are in the relative frequencies of the different weather types. Barry (1967) argued that the emphasis on site details obscures the essential similarities and that, with few exceptions, diffusivity differences are insignificant for practical purposes. Barry cited the work of Bryant, who after studying the frequencies of different classes of weather at various sites in England, Wales and Scotland concluded that the means are probably representative of conditions throughout the United Kingdom as a whole. Barry also cited some work of Singer and Smith who found that the dispersion conditions on the shores of Lake Ontario were similar to those they had found earlier on Long Island. Baulch (1962) claimed that the frequencies of gustiness classes at Nashville, Tennessee would have been the same as for Long Island, had the sampling statistics been better. Indeed, the frequencies of the Pasquill-Turner stability categories at Alberta stations are remarkably similar.

Thus, it is possible to define a standard site in terms of the dispersive properties of the atmosphere. If the statistical approach were adopted, then a typical (or actual) frequency distribution of meteorological variables could be used to generate estimates of the concentrations. These in turn would be fitted to a suitable

cumulative distribution function. Besides the problem of deciding the acceptable risk in the first place, there will be some difficulty in ascertaining whether or not compliance has been demonstrated because predictions of values at the extreme end of a probability distribution function are very sensitive to the fit of the data to the proposed distribution. Order of magnitude errors may be encountered when the data are forced to fit the wrong distribution. Also, small errors in input data can lead to large errors in conclusions about concentrations far out on the tail of the distribution curve. Aside from these problems a tremendous amount of work would have to be expended for even the smallest facility.

The enumerative approach offers several possibilities. Again a typical or actual joint frequency distribution of meteorological variables could be used to calculate all possible concentrations. The maximum would then be selected for comparison with the ambient air quality objective. If actual distributions are used there is some question about the period of record that should be employed to get representative values. Typing schemes may not provide an exhaustive list of possible conditions. Calculation methods become more questionable as the number of different conditions increases. In many instances none of the appropriate data will be available. Where they are, the computational task will be onerous.

Alternatively, one could try to identify the conditions under which the highest ground level concentrations would occur. For obvious reasons, no "absolute worst case" could ever be identified. "Worst"

would have to relate to one of a finite set of weather types and/or periods of record. Again errors in input data could have serious consequences and differences in calculation methods could lead to widely disparate conclusions.

A more practical approach relies heavily upon experience and uses relatively simple calculations that are known to design stacks such that ambient concentrations are generally well below the air quality objectives. This technique has also been called the "method of most probable maximum concentration", but it must be recognized that it may not be possible to assign exact numerical values to all of the probabilities involved. Such pragmatism is warranted because of the tremendous uncertainties in the prediction of atmospheric behavior. Many years of experience and application of the Principle of Simplicity (sometimes called Occam's Razor) have lead to a set of formulas and rules for stack design that are herein referred to as "Alberta Environment's Prescribed Methods".

1.4 WHY PRESCRIBED METHODS?

The Prescribed Methods can be viewed as a screening mechanism to distinguish problems from non-problems. (This is sometimes called the first hierarchy of models; EPA, 1977). Such simple, conservative, jurisdiction - wide methods achieve three goals:

(1) They can quickly demonstrate that a stack will meet the ambient air quality objective, and thereby hasten the approval process.

(2) They provide the means whereby small industrial facilities may design their stacks without a disproportionate expense on data collection and analysis.

(3) They indicate where potential problems exist. The option is then open to the applicant either;

  (i) to alter the stack design, or

  (ii) to implement a research program involving field measurements and refined modeling techniques for a more realistic assessment of air quality impact.

The second option in (3) has a side benefit in that it stimulates scientific efforts that will tend to improve our understanding of atmospheric processes. If the Prescribed Methods are too conservative, then too few "non-problems" are identified and Alberta Environment will be burdened with the review of numerous applications containing special studies and proposed alternative methods. Pressure is thereby maintained for periodic revisions of the Prescribed Methods to make them more realistic and reduce extravagant over designing.

2. WHAT TO AVOID

2.1 STACK AERODYNAMIC DOWNWASH

"Downwash", "creep" or "flagging", as it is variously called, will occur when the wind speed at stack height exceeds the exit speed of gases from the stack.

Wind regimes vary considerably throughout the province. A study of the wind speed climatology at the proposed site should be made and a stack exit speed chosen that will prevent downwash from occurring for better than 99% of the time. In other words, downwash may occur less than 1% of the time.

One of the following sources of wind data should be used (in decreasing order of preference):

(a) measurements on site at stack height

(b) measurements on site at standard ten metre height corrected to stack height using a power law appropriate for the terrain roughness and average stability

(c) measurements from a nearby airport weather station or air quality monitoring site corrected to stack height as in (b).

As a rule of thumb, exit speeds in excess of 15 m/s will usually be adequate in the province of Alberta except in the southwest region where an exit speed in excess of 20 m/s is recommended.

Often there will be no downwash problem at full throughput, but during periods of reduced stack gas flow the chances of downwash

are much greater. If stack flows will be variable or frequently less than maximum for which application is being made, then consideration should be given to designs that maintain the exit speed under these conditions. Possibilities include multiple flues and adjustable nozzles. It has been found that a horizontal disc one stack diameter in breadth around the rim of the stack top will prevent downwash in cases where very low exit speeds are unavoidable. Also, it may be possible to tailor the shape of the exit speed profile so as to increase the wind speed required to cause downwash.

2.2 BUILDING DOWNWASH

Let ℓ_b, a characteristic length, be the lesser of building height, h_b, or maximum building width perpendicular to the wind, w_b, (generally a diagonal). If the stack is within 3 ℓ_b of the building, then plumes will escape the building influence completely if the stack height, h_s, is given by:

$$h_s = h_b + 1.5\ \ell_b$$

Generally, this is the minimum stack height allowed. For squat buildings this is identical with the well-known 2 1/2 times rule.

If this minimum height is far in excess of what would be needed to meet the ambient air quality objectives, this criterion can be relaxed somewhat, but in subsequent calculations of ground level concentrations the flow displacement must be accounted for by reducing the initial stack height to:

$$h_s' = 2\ h_s - (h_b + 1.5\ \ell_b)$$

In no case may a stack ever be less than:

$$h_{s\ min} = h_b + 0.5\ \ell_b$$

2.3 TOPOGRAPHIC DOWNWASH

Step-like topographic features can influence a plume in much the same way as does a building. When the wind blows from the higher ground over the step, flow separation occurs and a counter-rotating eddy or cavity will develop in the lee. The effluent from a stack can either be trapped and recirculated in the cavity or simply brought to the ground in the turbulent descending flow of the wake. Unfortunately these effects are difficult to predict. As a rough rule of thumb, the stack should be located a minimum distance away from the terrain step equal to ten times the rise in terrain height. However, there is evidence that considerably larger distances - up to fifty times the terrain rise - may be required in some instances (Briggs, 1973). Plume buoyancy may well assist in preventing topographic downwash, but little is known about this effect at the present time.

For proposed locations in steep walled valleys or near ridges of hills the potential for terrain downwash should be investigated. Large wind tunnels can be used for this purpose. Alternatively, on site observations could be made using smoke, no lift balloons or other flow visualization or determination techniques during periods when the wind blows from the terrain step to the stack location. A range of wind speeds under typical weather conditions should be examined.

For very short stacks located in clearings in a tree canopy, the minimum height with respect to the tree canopy shall be given by:

$$h_s = h_{tree} - 0.1\, x_{tree}$$

where h_{tree} is the height of the tree canopy.

x_{tree} is the shortest distance between the stack and the tree canopy.

3. MEETING THE ALBERTA AMBIENT AIR QUALITY OBJECTIVES

While experience has shown that stacks designed in accordance with the Prescribed Methods are generally satisfactory in maintaining ambient air quality, it must be stressed that there is no guarantee that this will always be the case. Unique circumstances of topography or climate can lead to air quality problems. If unusual conditions are anticipated, stack design should proceed according to one of the Alternative Methods discussed later in this document.

Once in awhile problems arise in unexpected situations. Herein lies one of the purposes of ambient air quality monitoring. Symptoms of stack inadequacy include: (a) unacceptable frequency of pollutant concentrations in excess of the air quality objectives, (b) vegetation damage, (c) complaints from local residents, (d) other undesirable environmental effects. If one or more of these symptoms appear, Alberta Environment will examine the total picture and if the stack is deemed inadequate, then corrective action will be required, even though the original stack may have been designed in accordance with the Prescribed Methods or an accepted Alternative Method. The merits of some overdesign should be considered in light of this risk. Minimum designs may save money in the short term but lead to costly corrective action in the future.

3.1 THE ALBERTA STANDARD SITE

The available data for the province of Alberta and current knowledge about plume dispersion (Alberta Environment, 1978) lead to the following assumptions for a standard Alberta site:

(a) *The plume is trapped between the ground and an elevated temperature inversion. The elevated inversion is completely impervious and its base coincides with the effective stack height.*

Elevated temperature inversions at the Edmonton Stony Plain upper air station occur about 18% of the time annually at 17:00 MST and about 13% of the time annually at 05:00 MST. The base of these inversions ranges between 200 and 400 m on the average. Maximum afternoon mixing heights in winter range from 400 m in southern Alberta to about 200 m in northern Alberta. In summer, the maximum afternoon mixing heights range from about 2,200 m in the south to 1,600 m in the north. This means that all plumes will be trapped in a finite mixing layer at some time or other. Since the mixing lid causes a significant increase in maximum ground level concentration only when it occurs at 1 to 1.25 effective stack heights, the frequency with which any given stack actually experiences trapping will be considerably less than the total occurrence frequency of elevated inversions (finite mixing layer heights). In the case of an evolving mixing layer, the trapping may be short-lived and the capping stable layer may not be a perfect reflector. Trapping will, at most, produce a factor of two increase in maximum ground level concentrations, provided that the plume rise is unaffected by the presence of the lid and the lid is a perfect reflector. This occurs when the base of the lid is at effective stack height.

The analysis of upper air data for Edmonton Stony Plain indicates that about 2% of elevated inversions have bases below 100 m. This means that mixing layers as shallow as 100 m occur in less than 0.4% of all soundings. For this reason, and because radiosonde data at heights up to 100 m are unreliable anyway, a lower limit of 100 m is imposed on the inversion base height in all calculations.

(b) The effective stack height is independent of downwind distance.

Put another way, the plume is assumed to rise immediately to an equilibrium height. Even crude observations reveal that buoyant plumes do not behave this way; an inclination to the horizontal is maintained for at least several stack heights downwind. The incorporation of such a plume tilt greatly complicates the mathematical representation of plume dispersion. However, it has been found that global maximum concentrations calculated using a variable height plume do not differ greatly from those calculated using a fixed height plume (Kumar and Djurfors, 1977; Csanady, 1973). The fixed height approach gives the maximum at a somewhat larger distance and for somewhat lower wind speeds than does the variable height approach. For simplicity in calculating overall ground level concentrations, the fixed height approach is adopted.

(c) Plume spreads within the mixed layer are equivalent to those for Pasquill stability category D as given in the revised curves of F. B. Smith for land surfaces with roughness in the order of one metre.

In Alberta, Pasquill stability category D occurs better than 50% of the time while more stable categories account for another 30%.

Much experimental data indicates that the plume spreads from elevated sources correspond to those of class C, C-D or D on the Pasquill-Gifford curves, whether or not that category is indicated from the surface winds and degree of insolation. Many complicating factors may be involved in producing these overall results.

In addition, the effect of roughness appears to be equivalent to that of instability. Thus the σ_z estimates for category D in terrain of roughness 100 cm are comparable to those for category C-D in terrain of roughness 10 cm.

A considerable advantage in using category D is that wind speed may be allowed to vary over a wide range of values under day or night conditions, without a sudden jump into another stability category when a threshold wind speed is exceeded.

Current techniques for determining the mixing height assume a statically neutral layer. If the mixing layer were more unstable, the capping inversion would be eroded from below (effectively driven aloft) and would no longer produce the doubling of the maximum ground level concentration.

The rough terrain assumption is applicable to forested regions and urban areas. Northern Alberta is largely forested and central Alberta is mixed parkland, both of which should yield a roughness of about one metre, perhaps more in the former, less in the latter. For the southern Alberta prairie, the roughness is probably closer to one centimeter. In such terrain, use of spread values for the larger roughness will cause a somewhat higher concentration to occur closer to the stack. The effect is not considered to be large enough to warrant special treatment.

(d) Wind speeds at anemometer height of ten metres may range over all values between 1 m/s and 20 m/s. The appropriate wind speeds for plume dispersion are those at physical stack height and these may be obtained by means of a power law with the exponent appropriate to neutral stability and rough terrain.

Even in the windy southwest of Alberta the ten metre wind speed exceeds 20 m/s only a little more than 50 hours per year or less than 0.6% of the time. In central and northern Alberta, this frequency falls to less than 2 hours per year or less than 0.02% of the time.

(e) Rugged terrain acts both to reduce the local height of the plume above the ground and to enhance the vertical spread of the plume.

Plume height reduction is expected on the basis of simple hydrodynamics. Supporting observations in near neutral and stable atmospheres are plentiful. (In unstable atmospheres the plume may well travel parallel to the terrain, or where there are strong upslope winds the plume may actually rise).

It is well-documented that plume spreads in complex terrain are much greater than over flat terrain. Plume spreads derived from turbulence measurements at several Alberta sites and plume tracking experiments at others largely support this conclusion. Wind tunnel studies indicate that in the strictly two-dimensional case, only the vertical spread is affected.

(f) A tree canopy represents a translation of ground level for plumes at heights equal to several canopy heights. For lower plumes, the canopy acts as a porous barrier.

When a plume approaches a tree canopy it is deflected up and over. However, some plume material does penetrate into the trunk space directly. This has been shown in both wind tunnel and field tests. Plume material is also able to diffuse downwards through the canopy.

3.2 EQUATIONS TO BE USED

3.2.1 Diffusion

The ground level concentration for plume trapping is given by: (Bierly and Hewson, 1962)

$$\chi = \frac{Q}{2\pi u \sigma_y \sigma_z} \left\{ 2 \exp \frac{-H^2}{2\sigma_z^2} + \sum_{n=1}^{n=N} \left[2 \exp \frac{-(-H - 2nL)^2}{2\sigma_z^2} + 2 \exp \frac{-(-H + 2nL)^2}{2\sigma_z^2} \right] \right\}$$

where

Q is the emission rate.

u is the wind speed, taken here to be the wind at the height of the (physical) stack.

H is the effective stack height (physical height plus plume rise).

σ_y, σ_z are the standard deviations of the Gaussian concentration distribution in the lateral (crosswind) and vertical directions.

L is the height of the base of the inversion layer, taken here to be equal to the effective stack height, that is $L = H$.

N is the number of reflections under consideration.

Turner (1970) stated that $N = 3$ or 4 is sufficient to include the important reflections.

3.2.2 Plume Rise

The final rise of a buoyancy dominated plume in a neutral atmosphere is given by: (Briggs, 1970)

$$h_{rb} = c_1 \, F^{1/3} \, (3.5 \, x^*)^{2/3} \, u^{-1}$$

where F is the buoyancy flux.

u is the wind speed at stack height.

c_1 is a dimensionless constant.

$$x^* = 14 \, F^{5/8} \text{ for } F \leq 55 \text{ m}^4\text{s}^{-3}$$

$$x^* = 34 \, F^{2/5} \text{ for } F > 55 \text{ m}^4\text{s}^{-3}$$

$$F = \frac{T_g - T_a}{T_g} \, g \, v_s \, r_s^2$$

where T_g is the exit temperature of the stack gases.

T_a is the mean ambient temperature.

v_s is the exit speed of the stack gases.

r_s is the stack radius.

g is the acceleration due to gravity.

The final rise of a pure momentum jet is given by:

$$h_{rm} = 6 \, \frac{v_s}{u} \, r_s$$

For stacks with low buoyancy the larger of the buoyancy rise or momentum rise is used, that is:

$$h_r = \text{larger} \left\{ \begin{matrix} c_1 \, 13 \, F^{3/4} \, u^{-1} \\ 6 \, v_s \, r_s \, u^{-1} \end{matrix} \right\}$$

For a flare, where exit characteristics are not well defined, the buoyancy flux is given by:

$$F = .000037\ Q_h$$

where Q_h is the dry heat emission in calories per second.

The heat emission is calculated using the low (net) heat values for the flare fuel gases and pollutant. Low heat values for gases typically present in the common hydrogen sulphide flare are given in Table 3-1.

Radiation losses are assumed to be 25% of the heat released (Brzustowski et al., 1975).

For a sour gas flare the flare gas/fuel mixture must have a combined heat value of greater than 9.0 MJ/m^3 to ensure adequate combustion.

The constant c_1 in the foregoing equations is chosen to be 1.2. This is only 75% of the value recommended by Briggs (1969). However, the value 1.2 reflects the lower end of the range of observations (Briggs, 1972) and allows for the tendency of an overhead inversion to suppress normal plume rise.

Table 3-1 Low Heat Values for Flare Gases

Gas	Low heat value at 15.6°C and 101.3 kpa
	(MJ/m^3)
methane	34.0
ethane	61.1
propane	88.8
butane	116.2
pentane +	138.2
Hydrogen Sulphide	22.2

3.2.3 Plume Spreads

The vertical spread estimates are from the F. B. Smith revised system (Pasquill, 1974) for roughness of order 100 cm, that is:

$$\sigma_z = \sigma_{zr}\left(\frac{x}{x_r}\right)^{P_z}$$

σ_{zr} = 50 m

P_z = 0.68

x_r = 1000 m

The crosswind spread estimates are from a power law fit (after Southwest Energy Federal Task Force) to the Pasquill-Gifford curve adjusted about one-half a stability category towards the unstable (C-D) to account for the increased roughness:

$$\sigma_y = \sigma_{yr}\left(\frac{x}{x_r}\right)^{P_y}$$

σ_{yr} = 85 m

P_y = 0.88

x_r = 1000 m

The vertical standard deviation is considered to be independent of sampling time. The horizontal standard deviations are for three minutes and are corrected to the specified averaging time (either one-half or one hour) by:

$$\sigma_{yt} = \sigma_{y180} \left(\frac{t}{180}\right)^{0.2} \qquad t \text{ in } s$$

σ_{y180} is the horizontal spread given by the power law above.

No corrections for buoyancy induced spread or wind shear effects are made.

3.2.4 Wind Speed

For rough terrain in neutral stability the wind speed is given by:

$$u_{z2} = u_{z1}\left(\frac{z2}{z1}\right)^{P_w}$$

z_1 is normally taken to be standard anemometer height of ten metres and, u_{z1} the "surface" wind speed.

This empirical power law is a good average representation of the wind speed profile over the whole boundary layer and integral relations based on this easily integrated law are not far from correct.

In neutral stability over terrain of roughness one metre the value of P_w is about 0.30.

3.2.5 Overall Maximum Ground Level Concentration - Flat Terrain, Single Source

Letting

$$H = h_s + \frac{B}{u}$$

$$\sigma_z = \sigma_{zr}\left(\frac{x}{x_r}\right)^{P_z}$$

$$\sigma_y = \sigma_{yr}\left(\frac{x}{x_r}\right)^{P_y}$$

in flat terrain with doubling due to limited mixing the maximum ground level concentration with respect to both downwind distance and wind speed is given by:

$$\chi_{mm} = \frac{2\,Q\,P_z \exp\left[\frac{-(P_z + P_y)}{2P_z}\right] h_s^{-P_y/P_z}}{\pi \frac{\sigma_{zr}}{x_r^{P_z}} \frac{\sigma_{yr}}{x_r^{P_y}} B\left[\frac{P_z\,(P_z + P_y)}{\left(\frac{\sigma_{zr}}{x_r^{P_z}}\right)^2 P_y^2}\right]^{\frac{P_z + P_y}{2P_z}}}$$

This value occurs at a distance:

$$x_{mm} = \left[\frac{P_z\,(P_z + P_y)}{\left(\frac{\sigma_{zr}}{x_r^{P_z}}\right)^2 P_y^2}\right]^{\frac{1}{2P_z}} h_s^{\frac{1}{P_z}}$$

For a critical wind speed of:

$$u_c = \frac{P_y}{P_z}\,\frac{B}{h_s} \quad \text{with} \quad H = \left(\frac{P_y + P_z}{P_y}\right) h_s$$

At any specified wind speed the maximum concentration is given by:

$$\chi_m = \frac{2\,Q \exp \frac{-(P_z + P_y)}{2P_z}}{\pi\, u \left(\frac{\sigma_{zr}}{x_r^{P_z}}\right)\left(\frac{\sigma_{yr}}{x_r^{P_y}}\right) \left[\frac{P_z\,(h + B/u)^2}{\left(\frac{\sigma_{zr}}{x_r^{P_z}}\right)(P_z + P_y)}\right]^{\frac{P_z + P_y}{2P_z}}}$$

and occurs at:

$$x_m = \left[\frac{P_z\, H^2}{\frac{\sigma_{zr}}{x_r^{P_z}}^2 (P_z + P_y)}\right]^{\frac{1}{2P_z}}$$

3.2.6 Multiple Stacks

The contribution of each plume is superimposed by simple addition. The inversion base is taken to be the level of the highest plume or 100 m, whichever is larger, thereby trapping all other plumes in the mixed layer. The combination of wind speed and distance that produces the overall maximum concentration is then found by searching through the specified range of wind speeds and distances. This is most conveniently done by computer (Section 3.4).

No enhancement of plume rise or reduction in net ground level concentration is allowed.

When designing installations it is beneficial to combine effluent in a single stack to achieve the greatest plume rise and dispersion.

3.2.7 Complex Terrain

Rolling terrain which rises above stack base is represented by a series of semi-circular cylinders with axes transverse to the incident airflow. The radius of the cylinders is equal to the elevation difference between the stack base and local ground level. Each cylinder is inserted into the flow by itself and the position of the plume streamline above the centre of the cylinder is then computed. These points are then connected to yield the trajectory of the plume above the terrain.

The height, z, of a streamline initially at height H above the centre of a semi-circular cylinder of radius h_t is given by:

$$z = \frac{H}{2} + \frac{1}{2}\left(H^2 + 4h_t^2\right)^{1/2}$$

and the elevation of the plume above local ground level is then:

$$H_e = z - h_t$$

$$= \frac{H}{2} - h_t + \frac{1}{2}\left(H^2 + 4h_t^2\right)^{1/2}$$

For simplicity it is further assumed that the effects of streamtube contraction and vertical spread enhancement balance each other. This means that the exponential factor is modified only by a correction to the effective stack height. The vertical spread in the denominator of the non-exponential factor is increased by a factor equal to the reciprocal of streamtube contraction. The enhancement ratio D_z is given by:

$$D_z = 1 + \frac{h_t^2}{z^2}$$

where h_t is the local terrain height.

z is the vertical coordinate of the plume centreline.

Table 3-2 gives the D_z values as a function of the parameter H_o/h_t where H_o is the initial plume height. The maximum enhancement is a factor of two, which is consistent with values reported for various sites within the province.

One important implication of this technique is that the effective plume height will, at most, be reduced to one-half its flat terrain value. This will occur wherever the elevation of a hill above stack base is much larger than the flat terrain plume height, irrespective of the distance of the hill from the stack. Because the maximum ground level concentration is proportional to $1/H^{1+P_y/P_z}$ there will be an increase of, at most, a factor of 4.9 over the flat terrain maximum. In such a situation the vertical spread enhancement is equal to a factor of two and serves to reduce the net possible increase. Hence, rolling countryside will cause, at most, about a 250% increase in maximum ground level concentrations.

Reducing the effective plume height causes the maximum ground level concentration to occur closer to the stack. In the extreme case of an effective plume height equal to one-half the flat terrain plume height, the maximum will occur 36% closer to the stack than in flat terrain. Thus, in order to realize the 250% increase in maximum ground level concentration, a large hill would have to occupy this position.

Table 3-2 Values of the vertical spread enhancement and streamtube contraction

$\frac{H_o}{h_t}$	streamtube contraction	vertical spread enhancement D_z
0.0	.500	2.00
0.1	.525	1.90
0.25	.562	1.78
0.5	.620	1.61
0.75	.676	1.45
1.0	.724	1.38
1.25	.765	1.31
1.5	.800	1.25
2.0	.853	1.17
3.0	.917	1.09

3.2.8 Tree Canopy

The airflow from a clearing to a tree canopy is represented by the three-dimensional potential flow past a sphere, where the air movement into the truck space is regarded as analogous to the airflow around the side of a sphere. The combined effect of streamline displacement and streamtube contraction is equivalent to a reduction of plume height above the obstacle. This "equivalent" plume height can be approximated by the actual plume height predicted for potential flow over a two-dimensional circular cylinder. The approximation is best in the two limiting cases of initial plume height much larger/smaller than obstacle height. For intermediate situations the approximation tends to overestimate the equivalent plume height, but nevertheless provides a convenient interpolation. The plume height equation is then identical to the one given in section 3.2.7 with the tree canopy height substituted for the terrain elevation.

3.3 PRESCRIBED PROCEDURES

3.3.1 Single Source, Flat Terrain, No Trees

Calculate the overall maximum concentration, the distance to the maximum and the critical wind speed by using the following formulas: (obtained by the appropriate substitutions into the equations of section 3.2)

(a) Overall maximum ground level concentration

$$\chi_{mm} = 0.20\ h_s^{-1.29}\ \frac{Q}{B}\ 10^6 \left(\frac{t}{180}\right)^{-0.20}$$

h_s in m, Q in m^3/s, χ in ppm, t in s

(b) Distance to the overall maximum ground level concentration

$$x_{mm} = 4.00\ h_s^{1.47} \quad h_s,\ x \text{ in m}$$

(c) Critical wind speed

$$u_c = 1.29\ \frac{B}{h_s} \quad h_s \text{ in m},\ u_c \text{ in m/s}$$

(d) Critical effective stack height

$$H_c = 1.77\ h_s$$

(e) Plume rise factor

$$B = 16\ F^{3/4} \quad \text{for} \quad F \leq 55\ m^4 s^{-3}$$

$$B = 29\ F^{3/5} \quad \text{for} \quad F > 55\ m^4 s^{-3}$$

$$F = \frac{T_g - T_a}{T_g}\ g\ v_s\ r_s$$

or $F = .000037\ Q_h$ for large heat sources

where Q_h is the dry heat emission in cal/s with allowance made for radiation losses.

For very small heat sources:

$$B = 6\ v_s\ r_s$$

if this gives a larger value for B than the foregoing.

The computer programs STACKS and FLARES in section 3.4 will also handle this simple case.

3.3.2 Single Source, Complex Terrain

(a) On a topographic map of the area surrounding the stack, draw concentric circles, centred on the stack, in radius increments of no more than 0.5 km out to a distance of about one hundred stack heights.

(b) Examine the elevations around the circumference of each circle and select the largest one, irrespective of direction from the stack. (Negative elevation differences are permitted as input to the computer programs, but they will be treated as zero in the calculations.)

(c) Prepare a table giving the elevation of the terrain above stack base at each distance.

(d) If the area is more than 50% treed, then it is considered to be forested. Determine the height of the tree canopy and the shortest distance between the stack and the tree canopy.

(e) Using the equations given in the preceding sections calculate the maximum concentration with respect to wind speed at each terrain distance. Wind speeds (at a height of ten metres) between 1.0 and 20.0 m/s in 0.5 m/s increments should be used. The largest of the resulting maximum concentrations is regarded to be the overall maximum ground level (or treetop) concentration.

A computer program for this purpose is given in section 3.4.

3.3.3 Multiple Sources

(a) Determine the direction to the most significant terrain features.

(b) Draw the "line of best fit" through the locations of the various stacks in the direction chosen above.

(c) Choose an origin at the base of one of the stacks or at some other convenient location along the line.

(d) Draw the perpendicular from each stack location to the line.

(e) Determine the distance from the origin to each intersection of the perpendicular with the "line of best fit". This is the "stack distance" that is input to the computer program.

(f) Tabulate the terrain elevations above the plane of the origin as a function of distance from the origin in increments of no more than 0.5 km out to about one hundred times the height of the tallest stack.

(g) If the area is more than 50% treed, then it is considered to be forested. Determine the height of the tree canopy and the distance from the origin to the tree canopy.

(h) If the bases of the stacks are at different elevations, determine the height of each stack above the plane of the origin.

(i) Use the computer program in section 3.4 to calculate the overall maximum ground level concentration.

(j) Repeat the above procedure for significant terrain features in other directions.

3.4 COMPUTER PROGRAMS

The Prescribed Methods have been incorporated intc two computer programs written in the language FORTRAN IV. The program entitled STACKS will calculate the overall maximum ground level concentration for any gaseous pollutant emitted from up to 20 different stacks along the same straight line. If the stack(s) specified on input are not tall enough, the height(s) required will be calculated automatically and printed out. The program entitled FLARES does much the same, but for hydrogen sulphide flares only.

When complex terrain is specified, two groups of output will appear. The first gives the overall maximum ground level concentration examining only those hills specified on input. The second gives the overall maximum ground level concentration in flat terrain. If the hills under consideration are quite distant, then the flat terrain overall maximum ground level concentration may be the controlling value. The user is cautioned to examine both pieces of information before drawing any conclusions.

Complete listings of the two programs follow this brief introduction. Each major step of the calculations takes place in a separate subprogram. Comments appearing before each subprogram describe its purpose and mode of operation. Key elements are further commented within each subprogram.

This more or less modular program design is flexible in that changes can be made to the input, output or data transfer portions of the program without affecting the dispersion formulations of the

Prescribed Methods. It is also possible to write entirely new programs to meet individual needs, using only those modules which reflect a formulation of the Prescribed Methods.

A sample output using hypothetical, but reasonable input data appears after each program. These data may be used for testing the programs once they are installed on a system. On the Alberta Government's IBM 370/168 Model 3 M.V.S. System a run with a single stack that is not quite tall enough will take less than ten seconds of CPU time.

INPUT DATA

PROGRAM: STACKS

LINE	COLUMNS	VARIABLE NAME	UNITS	FORMAT	PROGRAM SYMBOL
1	1 - 80	Identifier (80 letters maximum)	-	20A4	ID
2	1, 2	Number of stacks (20 maximum)	-	I2	NSTACK
	3, 4	Number of distances with elevation differences (50 maximum)	-	I2	NX
	11 - 20	Ambient temperature	°C	F10.4	TA
	21 - 30	Averaging time	h	F10.4	AVTH
	31 - 40	Maximum Permissible Concentration	ppm	F10.4	STD
	41 - 50	Tree canopy height	m	F10.4	TREE
	51 - 60	Distance to tree canopy from the origin	m	F10.4	XTREE
3	1 - 10	Stack height	m	F10.1	HS
	11 - 20	Stack exit diameter	m	F10.4	D
	21 - 30	Stack gas exit temperature	°C	F10.1	TG
	31 - 40	Stack gas exit speed	m/s	F10.1	VS
	41 - 50	Pollutant flow rate at 101.325 kpa and reference temperature	m^3/s	F10.7	QREF
	51 - 60	Reference temperature	°C	F10.1	TREF
	61 - 70	Stack distance from (arbitrary) origin	m	F10.1	XLOC
2+NSTACK		same as line 3 for other stacks			
3+NSTACK	1 - 10	Distance from origin	m	F10.0	X
	11 - 20	Elevation above stack base	m	F10.0	XE
2+NSTACK +NX		same as line 3+NSTACK for other distances			

Data set may be repeated as required

```
C  ALBERTA DEPARTMENT OF THE ENVIRONMENT, ENVIRONMENTAL PROTECTION SERVICES
C  PRESCRIBED METHOD FOR STACK DESIGN - SEPTEMBER, 1978
C                  PROGRAM NAME:  STACKS
C
C  THE MAINLINE READS THE CONTROL DATA, STACK PARAMETERS AND TOPOGRAPHIC
C  INFORMATION.  THE VALUES OR THEIR MEANINGS ARE DISPLAYED IMMEDIATELY.
C  THE MAINLINE THEN ROUTES THE DATA TO THE APPROPRIATE SUBROUTINES FOR
C  COMPUTATION OF THE OVERALL MAXIMUM GROUND-LEVEL OR TREE-TOP CONCENTRA-
C  TION AND RELATED QUANTITIES.  IF THIS MGLC IS GREATER THAN THE MAXIMUM
C  PERMISSIBLE CONCENTRATION, A SUBROUTINE IS CALLED TO DETERMINE THE
C  REQUIRED STACK HEIGHT.  ALL SUBROUTINES USE A NUMBER OF FUNCTIONS.
C  ALL CONSTANTS ARE ASSIGNED THEIR VALUES IN THE BLOCK DATA SUBPROGRAM.
C
C  SEARCHES USE INCREMENTS OF 'UINC' BETWEEN THE TEN-METRE WINDSPEEDS
C  SPECIFIED BY 'US' AND 'UF', AND, IN FLAT TERRAIN, USE LOGARITHMIC
C  INCREMENTS OF DISTANCE.  SUCH DISCRETIZATION MAY CAUSE SOME SMALL
C  DIFFERENCES IN RESULTS IF IDENTICAL SITUATIONS ARE APPROACHED
C  THROUGH DIFFERENT SECTIONS OF THE PROGRAM OR IF DIFFERENT INCREMENT
C  SIZES ARE USED.
C
0001          DIMENSION X(50),XE(50),ID(20),HS(20),D(20),XLOC(20),VS(20),TG(20),
             *QREF(20),H(20),HCRIT(20),HEFF(20),UHS(20),CHI(20),CHIM(20),TREF(20
             *),Q(20)
0002          COMMON /ELINV/TYP2P1/LOOP/US,UF,UINC,ZA
0003       10 READ(5,20,END=370) (ID(I),I=1,20)
0004       20 FORMAT(20I4)
0005          READ(5,30) NSTACK,NX,TA,AVTH,STD,TREE,XTREE
0006       30 FORMAT(2I2,6X,5F10.4)
0007          DO 45 J=1,NSTACK
0008C         READ(5,40) HS(J),D(J),TG(J),VS(J),QREF(J),TREF(J),XLOC(J)
0009       40 FORMAT(F10.1,F10.4,2F10.1,F10.7,2F10.1)
0010       45 CONTINUE
0011          IF(NX.EQ.0) GOTO 65
0012          DO 60 I=1,NX
0013C         READ(5,70) X(I),XE(I)
0014       70 FORMAT(2F10.0)
0015       60 CONTINUE
0016       65 AVT=AVTH*3600.
0017          WRITE(6,90)
0018       90 FORMAT('1','ALBERTA DEPARTMENT OF THE ENVIRONMENT, PRESCRIBED METH
             *OD FOR STACK DESIGN')
0019          WRITE(6,100) (ID(I),I=1,20)
0020      100 FORMAT(' -',5X,20A4)
0021          DO 85 J=1,NSTACK
0022          WRITE(6,110) J, HS(J),D(J),VS(J),TG(J),QREF(J),TREF(J),XLOC(J)
0023      110 FORMAT(' -','PARAMETERS FOR STACK NUMBER',1X,I2/
             *'0',10X,'STACK HEIGHT =',F9.1,2X,'M'/
             *' ',8X,'STACK DIAMETER =',F9.3,2X,'M'/
             *' ',8X,'GAS EXIT SPEED =',F9.0,2X,'M/S'/
             *' ',7X,'GAS TEMPERATURE =',F9.0,2X,'C'/
             *' ',9X,'EMISSION RATE =',F9.6,2X,'M**3/S AT REFERENCE TEMPERATURE
             *AND 101.325 KPA'/
             *' ',1X,'REFERENCE TEMPERATURE =',F9.1,2X,'C'/
             *' ',8X,'STACK DISTANCE =',F9.0,2X,'M FROM ORIGIN'/)
0024          Q(J)=QREF(J)*(TA+273.16)/(TREF(J)+273.16)
0025       85 CONTINUE
0026          WRITE(6,315) TA
0027      315 FORMAT(' -',3X,'AMBIENT TEMPERATURE =',F6.0,2X,'C')
0028      360 WRITE(6,180)TYP2P1
0029      180 FORMAT('-',' ','DIFFUSION WITHIN A MIXING LAYER BENEATH AN ELEVATED IN
             *VERSION'/' ',' ','INVERSION BASE AT LEVEL OF HIGHEST PLUME OR',F6.0,2X
             *,'M, WHICHEVER IS LARGER')
0030          WRITE(6,181) US,UF,UINC
0031      181 FORMAT('0',' TEN-METRE WINDSPEEDS BETWEEN',F5.1,1X,'AND',F5.1,
             *1X,'M/S IN INCREMENTS OF',F5.1,1X,'M/S ARE EXAMINED')
0032          IF(NX.EQ.0) GOTO 345
0033          WRITE(6,310)
0034      310 FORMAT(' -',5X,'DISTANCE FROM ORIGIN',10X,'ELEVATION ABOVE ORIGIN')
0035          WRITE(6,320)
0036      320 FORMAT(' ',10X,'IN METRES',22X,'IN METRES'/)
0037          DO 340 KX=1,NX
0038          WRITE(6,330) X(KX),XE(KX)
0039      330 FORMAT(' ',9X,F8.0,24X,F8.0)
```

```
0040            340  CONTINUE
0041            345  IF(NX.EQ.0) WRITE(6,346)
0042            346  FORMAT('-','FLAT, ROUGH TERRAIN'/
                *' ',' (SEARCH IS PERFORMED USING EQUAL LOGARITHMIC INCREMENTS OF DI
                *STANCE)')
0043                 IF(TREE.GT.0.) WRITE(6,170) TREE,XTREE
0044            170  FORMAT('-',2X,'HEIGHT OF TREE CANOPY =',F6.0,2X,'M'/
                *' ',' DISTANCE TO TREE CANOPY =',F6.0,2X,'M FROM ORIGIN')
0045                 IF(NX.GT.0) CALL HILMAX(D,VS,TG,TA,HS,Q,X,XE,NX,CHIMAX,XMAX,
                *UCRIT,HCRIT,AVT,XLOC,NSTACK,CHIM,TREE,XTREE)
0046                 IF(NX.EQ.0) CALL FLAMAX(D,VS,TG,TA,HS,Q,CHIMAX,XMAX,UCRIT,
                *HCRIT,AVT,XLOC,NSTACK,CHIM,TREE,XTREE)
0047                 IF(TREE.LE.0.) WRITE(6,400) CHIMAX,AVTH
0048            400  FORMAT('-','OVERALL MAXIMUM GROUND-LEVEL CONCENTRATION =',
                *F8.3,2X,'PPM AS A',F5.2,1X,'HOUR AVERAGE')
0049                 IF(TREE.GT.0.) WRITE(6,405) CHIMAX,AVTH
0050            405  FORMAT('-',5X,'OVERALL MAXIMUM TREETOP CONCENTRATION =',
                *F8.3,2X,'PPM AS A',F5.2,1X,'HOUR AVERAGE')
0051                 WRITE(6,410) XMAX
0052            410  FORMAT(' ',20X,'DISTANCE OF OCCURRENCE =',F8.0,2X,'M')
0053                 WRITE(6,430) UCRIT
0054            430  FORMAT(' ',14X,'CRITICAL TEN-METRE WINDSPEED =',F8.1,2X,'M/S')
0055                 IF(XMAX.LT.XTREE) WRITE(6,435)
0056            435  FORMAT('0','*** NOTE - THE MAXIMUM ACTUALLY OCCURS AT GROUND-LEVEL
                * BETWEEN THE ORIGIN AND THE TREES ***')
0057                 WRITE(6,414) STD,AVTH
0058            414  FORMAT('-',' MAXIMUM PERMISSIBLE CONCENTRATION =',F6.3,1X,'PPM AS A
                *',F5.2,1X,'HOUR AVERAGE')
0059                 WRITE(6,415)
0060            415  FORMAT('-',' STACK',6X,'EFFECTIVE STACK',5X,'CONTRIBUTION TO OVERAL
                *L'/' ','NUMBER',5X,'HEIGHT (M)',10X,'MAXIMUM (PPM)'/)
0061                 DO 420 J=1,NSTACK
0062                 WRITE(6,416) J,HCRIT(J),CHIM(J)
0063            416  FORMAT(' ',I2,12X,F8.0,17X,F8.3)
0064            420  CONTINUE
0065            425  IF(CHIMAX.GT.STD) CALL REQHS(D,VS,TG,TA,HS,Q,X,XE,NX,STD,AVT,TREE,
                *XTREE,XLOC,NSTACK)
0066                 NX=NX
0067                 IF(NX.GT.0) NX=0
0068                 IF(NX.GT.0) GOTO 65
0069                 GOTO 10
0070            370  STOP
0071                 END
```

```
C
C  THE FUNCTION 'RISE' GIVES THE PLUME RISE DUE TO BUOYANCY OR MOMENTUM
C  ACCORDING TO THE FINAL RISE FORMULAS OF BRIGGS(1970)
C
      FUNCTION RISE(R,VS,TG,TA,UHS)
      COMMON /BRIGGS/C1,G,CM
      TGK=TG+273.16
      TAK=TA+273.16
      F=G*R*VS*(TGK-TAK)/TGK
      IF(F.LE.55.) XSTAR=14.*F**0.625
      IF(F.GT.55.) XSTAR=34.*F**0.4
      HRB=C1*F**(1./3.)*(3.5*XSTAR)**(2./3.)/UHS
      HRM=CM*2.*R*VS/UHS
      RISE=AMAX1(HRB,HRM)
      RETURN
      END
```

```
C
C  THE FUNCTION 'FOTFLO' GIVES THE HEIGHT OF A PLUME ABOVE A CIRCULAR
C  CYLINDER OF INFINITE CROSSWIND EXTENT WITH RADIUS EQUAL TO THE LOCAL
C  ELEVATION OF THE TERRAIN ABOVE STACK BASE
C
0001        FUNCTION FOTFLO(HT,H)
0002        IF(HT.LE.0.0) GOTO 20
0003        FOTFLO=H/2.-HT+0.5*SQRT(H*H+4.*HT*HT)
0004        RETURN
0005     20 FOTFLO=H
0006        RETURN
0007        END
```

```
                C
                C  THE SUBROUTINE 'HILMAX' COMPUTES THE OVERALL MAXIMUM GROUND-LEVEL OR
                C  TREE-TOP CONCENTRATION FOR COMPLEX TERRAIN WHERE THE DISTANCES AND
                C  LOCAL ELEVATION DIFFERENCES HAVE BEEN SPECIFIED
                C
0001                 SUBROUTINE HILMAX(D,VS,TG,TA,HS,Q,X,XE,NX,CHIMAX,XMAX,UCRIT,HCRIT,
                    *AVT,XLOC,NSTACK,CHIM,TREE,XTREE)
0002                 DIMENSION XE(50),X(50),D(20),VS(20),TG(20),HS(20),Q(20),H(20),UHS(
                    *10),XLOC(20),HEFF(20),HCRIT(20),CHI(20),CHIM(20)
0003                 COMMON /ELINV/TYP2P1/LOOP/US,UF,UINC,ZA
0004                 CHIMAX=0.0
0005                 U=US
0006                 IUF=IFIX((UF-US)/UINC)+1
0007                 DO 30 IU=1,IUF
0008                 DO 15 J=1,NSTACK
0009                 UHS(J)=WDSFD(U,HS(J),ZA)
0010                 R=D(J)/2.
0011                 H(J)=HS(J)+RISE(R,VS(J),TG(J),TA,UHS(J))
0012              15 CONTINUE
0013                 DO 20 KX=1,NX
0014                 IF(X(KX).LT.XTREE) XET=XE(KX)
0015                 IF(X(KX).GE.XTREE) XET=XE(KX)+TREE
0016                 HMAX=0.0
0017                 DO 25 J=1,NSTACK
0018                 HEFF(J)=POTFLO(XET,H(J))
0019                 IF(HEFF(J).LE.HMAX) GOTO 25
0020                 HMAX=HEFF(J)
0021              25 CONTINUE
                C  THE PRECEDING LOOP CHOOSES THE LEVEL OF THE HIGHEST PLUME.  THE MIXING
                C  LAYER DEPTH IS THEN SET EQUAL TO THIS OR TO THE VALUE CONTAINED IN
                C  'TYP2P1', WHICHEVER IS LARGER.
0022                 DML=AMAX1(HMAX,TYP2P1)
0023                 CONCN=0.0
0024                 DO 26 J=1,NSTACK
0025                 XREL=X(KX)-XLOC(J)
0026                 IF(XREL.LE.0.) CHI(J)=0.0
0027                 IF(XREL.LE.0.) GOTO 26
                C  THE VARIABLE 'DZ' IS THE VERTICAL SPREAD ENHANCEMENT FACTOR WHICH IS
                C  SET EQUAL TO THE RECIPROCAL OF THE STREAMTUBE CONTRACTION DUE TO THE
                C  PRESENCE OF THE ELEVATED TERRAIN ALONE
0028                 IF(XE(KX).GT.0.) DZ=1.+(XE(KX)*XE(KX))/(HEFF(J)+XE(KX))**2.
0029                 IF(XE(KX).LE.0.) DZ=1.
0030                 CHI(J)=(1./DZ)*TRAP(Q(J),UHS(J),XREL,HEFF(J),DML,AVT)
0031                 CONCN=CONCN+CHI(J)
0032              26 CONTINUE
0033                 IF(CONCN.LE.CHIMAX) GOTO 20
0034                 CHIMAX=CONCN
0035                 XMAX=X(KX)
0036                 UCRIT=U
0037                 DO 40 J=1,NSTACK
0038                 CHIM(J)=CHI(J)
0039              40 HCRIT(J)=HEFF(J)
0040              20 CONTINUE
0041                 U=U+UINC
0042              30 CONTINUE
0043                 RETURN
0044                 END
```

```
C
C  THE FUNCTION 'TRAP' GIVES THE GROUND-LEVEL OR TREE-TOP CONCENTRATION
C  DUE TO PLUME TRAPPING USING THE GAUSSIAN PLUME FORMULA WITH TEN
C  REFLECTIONS BETWEEN THE SURFACE AND THE ELEVATED INVERSION
C
0001        FUNCTION TRAP(Q,UHS,X,H,DML,AVT)
0002        COMMON /PLAW/PY,PZ,SIGZR,XREF,SIGYR,PT
0003        SIGMAZ=SIGZR*(X/XREF)**PZ
0004        SIGMAY=SIGYR*(X/XREF)**PY
0005        SIGMAY=SIGMAY*(AVT/180.)**PT
C  THE PRECEDING LINE IS THE AVERAGING TIME CORRECTION.  IT IS APPLIED
C  TO THE CROSSWIND PLUME SPREAD ONLY.
0006        SUM=0.0
0007        DO 10 N=1,10
0008        S1=(-H-2.*FLOAT(N)*DML)/SIGMAZ
0009        S2=(H-2.*FLOAT(N)*DML)/SIGMAZ
0010        IF(ABS(S1).GT.10.0) S1=10.0
0011        IF(ABS(S2).GT.10.0) S2=10.0
0012        SUM=SUM+2.*EXP(-0.5*S1*S1) + 2.*EXP(-0.5*S2*S2)
0013     10 CONTINUE
0014        S3=H/SIGMAZ
0015        IF(ABS(S3).GT.10.) S3=10.
0016        F1=Q*1000000./(2.*3.14159*UHS*SIGMAZ*SIGMAY)
0017        F2=2.*EXP(-0.5*S3*S3) + SUM
0018        TRAP=F1*F2
0019        RETURN
0020        END
```

```
C
CC  THE BLOCK DATA SUBPROGRAM ASSIGNS VALUES TO ALL CONSTANTS AND SOME
CC  CONTROL VARIABLES FOR USE THROUGHOUT THE PROGRAM
C
0001        BLOCK DATA
0002        COMMON /PLAW/PY,PZ,SIGZR,XREF,SIGYR,PT/ELINV/TYP2P1/BRIGGS/C1,G,CM
           */LOOP/US,UF,UINC,ZA/WIND/FW/DIST/STPLCS
0003        DATA SIGZR/50./,XREF/1000./,PZ/0.68/,SIGYR/85./,PY/0.88/,TYP2P1/10
           *0./,US/1./,UF/20./,ZA/10./,PW/0.3/,PT/0.2/,C1/1.2/,G/9.8/,CM/3.0/,
           *UINC/0.5/,STPLCS/0.04/
0004        END
```

```
                C
                C  SUBROUTINE 'FLAMAX' COMPUTES THE OVERALL MAXIMUM GROUND-LEVEL OR
                C  TREE-TOP CONCENTRATION FOR FLAT TERRAIN BY SEARCHING THROUGH
                C  THE SPECIFIED WIND SPEEDS AND THE APPROPRIATE DISTANCES.  THE
                C  DISTANCE SEARCH USES LOGARITHMIC DISTANCE INCREMENTS SPECIFIED BY
                C  THE CONTROL PARAMETER 'STPLOG'.  THIS ALLOWS FOR VARIABLE RESOLUTION,
                C  FINE AT SHORT RANGE, PROGRESSIVELY COARSER AT LONGER RANGES WHERE
                C  THE CONCENTRATIONS ARE NOT AS SENSITIVE TO DISTANCE.  SEARCH TIME IS
                C  FAR LESS THAN WOULD BE REQUIRED WITH FIXED DISTANCE INCREMENTS.
                C
0001                    SUBROUTINE FLAMAX(D,VS,TG,TA,HS,Q,CHIMAX,XMAX,UCRIT,HCRIT,AVT,
                       *XLOC,NSTACK,CHIM,TREE,XTREE)
0002                    DIMENSION D(20),VS(20),TG(20),HS(20),Q(20),H(20),UHS(20),XLOC(20),
                       *HCRIT(20),CHI(20),CHIM(20),HEFF(20)
0003                    COMMON /ELINK/TYP2P1/PLAN/PT,PZ,SIGZR,XREF,SIGYR,PT/LOOP/US,UF,
                       *UINC,ZA/DIST/STPLOG
0004                    CALL LIMIT(HS,IXS,IXF,NSTACK,D,VS,TG,TA,TREE,XLOC)
0005                    CHIMAX=0.0
0006                    U=US
0007                    IUF=IFIX((UF-US)/UINC)+1
0008                    DO 30 IU=1,IUF
0009                    DO 15 J=1,NSTACK
0010                    UHS(J)=ADJFD(U,HS(J),ZA)
0011                    R=D(J)/2.
0012                    H(J)=HS(J)+RISE(R,VS(J),TG(J),TA,UHS(J))
0013                 15 CONTINUE
0014                    DO 20 IX=IXS,IXF
0015                    X=10.**(1. + STPLOG*FLOAT(IX))
0016                    HMAX=0.0
0017                    DO 25 J=1,NSTACK
0018                    IF(X.LT.XTREE) HEFF(J)=H(J)
0019                    IF(X.GE.XTREE) HEFF(J)=POTFLO(TREE,H(J))
                C  THE PRECEDING LINE IS THE PLUME HEIGHT CORRECTION FOR THE PRESENCE
                C  OF A TREE CANOPY.
0020                    IF(HEFF(J).LE.HMAX) GOTO 25
0021                    HMAX=HEFF(J)
0022                 25 CONTINUE
0023                    DML=AMAX1(HMAX,TYP2P1)
0024                    CONCN=0.0
0025                    DO 26 J=1,NSTACK
0026                    XREL=X-XLOC(J)
0027                    IF(XREL.LE.0.) CHI(J)=0.0
0028                    IF(XREL.LE.0.) GOTO 26
0029                    CHI(J)=TRAP(Q(J),UHS(J),XREL,HEFF(J),DML,AVT)
0030                    CONCN=CONCN+CHI(J)
0031                 26 CONTINUE
0032                    IF(CONCN.LE.CHIMAX) GOTO 20
0033                    CHIMAX=CONCN
0034                    XMAX=X
0035                    UCRIT=U
0036                    DO 40 J=1,NSTACK
0037                    CHIM(J)=CHI(J)
0038                 40 HCRIT(J)=HEFF(J)
0039                 20 CONTINUE
0040                    U=U+UINC
0041                 30 CONTINUE
0042                    RETURN
0043                    END
```

```
C
C  THE SUBROUTINE 'REQHS' CALCULATES THE STACK HEIGHT(S) NEEDED TO KEEP
C  THE OVERALL MAXIMUM GROUND-LEVEL CONCENTRATION AT OR BELOW THE MAXIMUM
C  PERMISSIBLE CONCENTRATION.  FOR STACK HEIGHTS LESS THAN 15.0 M,
C  INCREMENTS OF 0.3 M ARE USED; FOR STACK HEIGHTS GREATER THAN OR EQUAL
C  TO 15.0 M AND LESS THAN 30.0 M, INCREMENTS OF 1.0 M ARE USED; FOR STACK
C  HEIGHTS GREATER THAN OR EQUAL TO 30.0 M, INCREMENTS OF 3.0 M ARE USED.
C
0001        SUBROUTINE REQHS(D,VS,TG,TA,HS,Q,X,XE,NX,STD,AVT,TREE,XTREE,XLOC,
           *NSTACK)
0002        DIMENSION X(50),XE(50),HS(20),D(20),VS(20),TG(20),Q(20),HCRIT(20)
           *,CHIM(20),HSRQ(20),XLOC(20)
0003        DO 5 I=1,NSTACK
0004      5 HSRQ(I)=HS(I)
0005     10 DO 15 J=1,NSTACK
0006        IF(HSRQ(J).LT.15.0) HSINC=0.3
0007        IF(HSRQ(J).GE.15.0.AND.HSRQ(J).LT.30.0) HSINC=1.0
0008        IF(HSRQ(J).GE.30.0) HSINC=3.0
0009        HSRQ(J)=HSRQ(J)+HSINC
0010     15 CONTINUE
0011        IF(NX.EQ.0) CALL FLAMAX(D,VS,TG,TA,HSRQ,Q,CHIMAX,XMAX,UCRIT,HCRIT,
           *AVT,XLOC,NSTACK,CHIM,TREE,XTREE)
0012        IF(NX.GT.0) CALL HILMAX(D,VS,TG,TA,HSRQ,Q,X,XE,NX,CHIMAX,XMAX,
           *UCRIT,HCRIT,AVT,XLOC,NSTACK,CHIM,TREE,XTREE)
0013        IF(CHIMAX.GT.STD) GOTO 10
0014        WRITE(6,21)
0015     21 FORMAT('-'/'-','***** TALLER STACK(S) NECESSARY *****')
0016        WRITE(6,30)
0017     30 FORMAT('-','STACK',6X,'REQUIRED STACK',5X,'EFFECTIVE STACK',5X,'CO
           *NTRIBUTION TO OVERALL'/' ','NUMBER',5X,'HEIGHT (M)',10X,'HEIGHT (M
           *)',10X,'MAXIMUM (PPM)'/)
0018        DO 35 J=1,NSTACK
0019        WRITE(6,31) J,HSRQ(J),HCRIT(J),CHIM(J)
0020     31 FORMAT(' ',I2,12X,F8.1,10X,F8.0,17X,F8.3)
0021     35 CONTINUE
0022        WRITE(6,40) XMAX
0023     40 FORMAT('0',12X,'DISTANCE TO MAXIMUM =',F8.0,2X,'M')
0024        WRITE(6,50) UCRIT
0025     50 FORMAT(' ',3X,'CRITICAL TEN-METRE WINDSPEED =',F8.1,2X,'M/S')
0026        RETURN
0027        END
```

```
C
C     THE FUNCTION 'WDSPD' GIVES THE WINDSPEED AT ANY HEIGHT USING A SIMPLE
C     POWER LAW AND THE WINDSPEED AT ANOTHER HEIGHT
C
      FUNCTION WDSPD(U1,Z2,Z1)
      COMMON /WIND/PW
      WDSPD=U1*(Z2/Z1)**PW
      RETURN
      END
```

```
C
C  THE SUBROUTINE 'LIMIT' DETERMINES THE LARGEST AND SMALLEST DISTANCES
C  BETWEEN WHICH THE FLAT TERRAIN OVERALL MAXIMUM GROUND-LEVEL CONCENTRA-
C  TION MUST LIE.  THIS RESTRICTS THE SEARCH AND SAVES ON COMPUTER TIME.
C
0001        SUBROUTINE LIMIT(HS,IXS,IXF,NSTACK,D,VS,TG,TA,TREE,XLOC)
0002        COMMON /PLAW/PY,PZ,SIGZR,XREF,SIGYR,PT/DIST/STPLOG/LOOP/US,UF,
           *UINC,ZA
0003        DIMENSION D(20),VS(20),TG(20),HS(20),H(20),XLOC(20)
0004        HMIN=99999.
0005        DO 10 J=1,NSTACK
0006        UFHS=WDSPD(UF,HS(J),ZA)
0007        R=D(J)/2.
0008        H(J)=HS(J)+RISE(R,VS(J),TG(J),TA,UFHS)
0009        H(J)=POTFLO(TREE,H(J))
0010        IF(H(J).GE.HMIN) GOTO 10
0011        HMIN=H(J)
0012     10 CONTINUE
0013        HMAX=0.0
0014        DO 20 J=1,NSTACK
0015        R=D(J)/2.
0016        USHS=WDSPD(US,HS(J),ZA)
0017        H(J)=HS(J)+RISE(R,VS(J),TG(J),TA,USHS)
0018        IF(H(J).LE.HMAX) GOTO 20
0019        HMAX=H(J)
0020     20 CONTINUE
0021        XLOCX=0.0
0022        DO 30 J=1,NSTACK
0023        IF(XLOC(J).LE.XLOCX) GOTO 30
0024        XLOCX=XLOC(J)
0025     30 CONTINUE
0026        XS=((PZ*HMIN*HMIN)/((PY+PZ)*(SIGZR/XREF**PZ)**2.))**(1./(2.*PZ))
0027        IXSMN=IFIX((ALOG10(XS)-1.0)/STPLOG)
0028        IXS=AMAX0(IXSMN,1)
0029        XF=((PZ*HMAX*HMAX)/((PY+PZ)*(SIGZR/XREF**PZ)**2.))**(1./(2.*PZ))+
           *XLOCX
0030        IXFMX=IFIX((ALOG10(XF)-1.0)/STPLOG)
0031        IMAX=IFIX(4/STPLOG)
0032        IXF=AMIN0(IXFMX,IMAX)
0033        RETURN
0034        END
```

ALBERTA DEPARTMENT OF THE ENVIRONMENT, PRESCRIBED METHOD FOR STACK DESIGN

ISOLATED LARGE EMITTER OF SO2

PARAMETERS FOR STACK NUMBER 1

STACK HEIGHT =	50.0	M
STACK DIAMETER =	5.000	M
GAS EXIT SPEED =	25.	M/S
GAS TEMPERATURE =	430.	C
EMISSION RATE =	0.350000	M**3/S AT REFERENCE TEMPERATURE AND 101.325 KPA
REFERENCE TEMPERATURE =	21.0	C
STACK DISTANCE =	0.	M FROM ORIGIN

AMBIENT TEMPERATURE = 21. C

DIFFUSION WITHIN A MIXING LAYER BENEATH AN ELEVATED INVERSION
INVERSION BASE AT LEVEL OF HIGHEST PLUME OR 100. M, WHICHEVER IS LARGER

TEN-METRE WINDSPEEDS BETWEEN 1.0 AND 20.0 M/S IN INCREMENTS OF 0.5 M/S ARE EXAMINED

DISTANCE FROM ORIGIN IN METRES	ELEVATION ABOVE ORIGIN IN METRES
500.	3.
1000.	6.
1500.	12.
2000.	12.
2500.	15.
3000.	15.
3500.	15.
4000.	30.
4500.	45.
5000.	45.
5500.	61.
6000.	61.
6500.	61.
7000.	61.
7500.	53.
8000.	61.
8500.	76.
9000.	76.
9500.	76.
10000.	76.

HEIGHT OF TREE CANOPY = 15. M
DISTANCE TO TREE CANOPY = 500. M FROM ORIGIN

OVERALL MAXIMUM TREETOP CONCENTRATION = 0.226 PPM AS A 0.50 HOUR AVERAGE
DISTANCE OF OCCURRENCE = 1500. M
CRITICAL TEN-METRE WINDSPEED = 14.5 M/S

MAXIMUM PERMISSIBLE CONCENTRATION = 0.200 PPM AS A 0.50 HOUR AVERAGE

STACK NUMBER	EFFECTIVE STACK HEIGHT (M)	CONTRIBUTION TO OVERALL MAXIMUM (PPM)
1	101.	0.226

***** TALLER STACK(S) NECESSARY *****

STACK NUMBER	REQUIRED STACK HEIGHT (M)	EFFECTIVE STACK HEIGHT (M)	CONTRIBUTION TO OVERALL MAXIMUM (PPM)
1	59.0	100.	0.199

DISTANCE TO MAXIMUM = 1500. M
CRITICAL TEN-METRE WINDSPEED = 16.0 M/S

ALBERTA DEPARTMENT OF THE ENVIRONMENT, PRESCRIBED METHOD FOR STACK DESIGN

ISOLATED LARGE EMITTER OF SO2

PARAMETERS FOR STACK NUMBER 1

STACK HEIGHT =	50.0	M
STACK DIAMETER =	5.000	M
GAS EXIT SPEED =	25.	M/S
GAS TEMPERATURE =	430.	C
EMISSION RATE =	0.350000	M**3/S AT REFERENCE TEMPERATURE AND 101.325 KPA
REFERENCE TEMPERATURE =	21.0	C
STACK DISTANCE =	0.	M FROM ORIGIN

AMBIENT TEMPERATURE = 21. C

DIFFUSION WITHIN A MIXING LAYER BENEATH AN ELEVATED INVERSION
INVERSION BASE AT LEVEL OF HIGHEST PLUME OR 100. M, WHICHEVER IS LARGER
TEN-METRE WINDSPEEDS BETWEEN 1.0 AND 20.0 M/S IN INCREMENTS OF 0.5 M/S ARE EXAMINED

FLAT, ROUGH TERRAIN
(SEARCH IS PERFORMED USING EQUAL LOGARITHMIC INCREMENTS OF DISTANCE)

HEIGHT OF TREE CANOPY = 15. M
DISTANCE TO TREE CANOPY = 500. M FROM ORIGIN

OVERALL MAXIMUM TREETOP CONCENTRATION = 0.203 PPM AS A 0.50 HOUR AVERAGE
DISTANCE OF OCCURRENCE = 1585. M
CRITICAL TEN-METRE WINDSPEED = 16.5 M/S

MAXIMUM PERMISSIBLE CONCENTRATION = 0.200 PPM AS A 0.50 HOUR AVERAGE

STACK NUMBER	EFFECTIVE STACK HEIGHT (M)	CONTRIBUTION TO OVERALL MAXIMUM (PPM)
1	101.	0.203

***** TALLER STACK(S) NECESSARY *****

STACK NUMBER	REQUIRED STACK HEIGHT (M)	EFFECTIVE STACK HEIGHT (M)	CONTRIBUTION TO OVERALL MAXIMUM (PPM)
1	53.0	101.	0.194

DISTANCE TO MAXIMUM = 1585. M
CRITICAL TEN-METRE WINDSPEED = 17.0 M/S

ALBERTA DEPARTMENT OF THE ENVIRONMENT, PRESCRIBED METHOD FOR STACK DESIGN

THREE SMALL EMITTERS OF NO2 IN CLOSE PROXIMITY

PARAMETERS FOR STACK NUMBER 1

STACK HEIGHT =	10.0	M
STACK DIAMETER =	0.304	M
GAS EXIT SPEED =	20.	M/S
GAS TEMPERATURE =	400.	C
EMISSION RATE =	0.000895	M**3/S AT REFERENCE TEMPERATURE AND 101.325 KPA
REFERENCE TEMPERATURE =	21.1	C
STACK DISTANCE =	0.	M FROM ORIGIN

PARAMETERS FOR STACK NUMBER 2

STACK HEIGHT =	10.0	M
STACK DIAMETER =	0.333	M
GAS EXIT SPEED =	20.	M/S
GAS TEMPERATURE =	400.	C
EMISSION RATE =	0.001073	M**3/S AT REFERENCE TEMPERATURE AND 101.325 KPA
REFERENCE TEMPERATURE =	21.1	C
STACK DISTANCE =	8.	M FROM ORIGIN

PARAMETERS FOR STACK NUMBER 3

STACK HEIGHT =	10.0	M
STACK DIAMETER =	0.360	M
GAS EXIT SPEED =	20.	M/S
GAS TEMPERATURE =	400.	C
EMISSION RATE =	0.001252	M**3/S AT REFERENCE TEMPERATURE AND 101.325 KPA
REFERENCE TEMPERATURE =	21.1	C
STACK DISTANCE =	15.	M FROM ORIGIN

AMBIENT TEMPERATURE = 21. C

DIFFUSION WITHIN A MIXING LAYER BENEATH AN ELEVATED INVERSION
INVERSION BASE AT LEVEL OF HIGHEST PLUME OR 100. M, WHICHEVER IS LARGER

TEN-METRE WINDSPEEDS BETWEEN 1.0 AND 20.0 M/S IN INCREMENTS OF 0.5 M/S ARE EXAMINED

DISTANCE FROM ORIGIN IN METRES	ELEVATION ABOVE ORIGIN IN METRES
50.	3.
100.	5.
150.	5.
200.	6.
250.	6.
300.	8.
350.	9.
400.	9.
450.	9.
500.	

HEIGHT OF TREE CANOPY = 10. M
DISTANCE TO TREE CANOPY = 100. M FROM ORIGIN

OVERALL MAXIMUM TREETOP CONCENTRATION = 0.555 PPM AS A 1.00 HOUR AVERAGE
DISTANCE OF OCCURRENCE = 100. M
CRITICAL TEN-METRE WINDSPEED = 4.0 M/S

MAXIMUM PERMISSIBLE CONCENTRATION = 0.210 PPM AS A 1.00 HOUR AVERAGE

STACK NUMBER	EFFECTIVE STACK HEIGHT (M)	CONTRIBUTION TO OVERALL MAXIMUM (PPM)
1	12.	0.168
2	13.	0.189
3	14.	0.198

***** TALLER STACK(S) NECESSARY *****

STACK NUMBER	REQUIRED STACK HEIGHT (M)	EFFECTIVE STACK HEIGHT (M)	CONTRIBUTION TO OVERALL MAXIMUM (PPM)
1	20.1	21.	0.062
2	20.1	23.	0.068
3	20.1	24.	0.071

DISTANCE TO MAXIMUM = 200. M
CRITICAL TEN-METRE WINDSPEED = 2.5 M/S

ALBERTA DEPARTMENT OF THE ENVIRONMENT, PRESCRIBED METHOD FOR STACK DESIGN

THREE SMALL EMITTERS OF NO2 IN CLOSE PROXIMITY

PARAMETERS FOR STACK NUMBER 1

STACK HEIGHT =	10.0	M
STACK DIAMETER =	0.304	M
GAS EXIT SPEED =	20.	M/S
GAS TEMPERATURE =	400.	C
EMISSION RATE =	0.000896	M**3/S AT REFERENCE TEMPERATURE AND 101.325 KPA
REFERENCE TEMPERATURE =	21.1	C
STACK DISTANCE =	0.	M FROM ORIGIN

PARAMETERS FOR STACK NUMBER 2

STACK HEIGHT =	10.0	M
STACK DIAMETER =	0.333	M
GAS EXIT SPEED =	20.	M/S
GAS TEMPERATURE =	400.	C
EMISSION RATE =	0.001073	M**3/S AT REFERENCE TEMPERATURE AND 101.325 KPA
REFERENCE TEMPERATURE =	21.1	C
STACK DISTANCE =	8.	M FROM ORIGIN

PARAMETERS FOR STACK NUMBER 3

STACK HEIGHT =	10.0	M
STACK DIAMETER =	0.360	M
GAS EXIT SPEED =	20.	M/S
GAS TEMPERATURE =	400.	C
EMISSION RATE =	0.001252	M**3/S AT REFERENCE TEMPERATURE AND 101.325 KPA
REFERENCE TEMPERATURE =	21.1	C
STACK DISTANCE =	15.	M FROM ORIGIN

AMBIENT TEMPERATURE = 21. C

DIFFUSION WITHIN A MIXING LAYER BENEATH AN ELEVATED INVERSION
INVERSION BASE AT LEVEL OF HIGHEST PLUME OR 100. M, WHICHEVER IS LARGER

TEN-METRE WINDSPEEDS BETWEEN 1.0 AND 20.0 M/S IN INCREMENTS OF 0.5 M/S ARE EXAMINED

FLAT, ROUGH TERRAIN
(SEARCH IS PERFORMED USING EQUAL LOGARITHMIC INCREMENTS OF DISTANCE)

HEIGHT OF TREE CANOPY = 10. M
DISTANCE TO TREE CANOPY = 100. M FROM ORIGIN

OVERALL MAXIMUM TREETOP CONCENTRATION = 0.505 PPM AS A 1.00 HOUR AVERAGE
DISTANCE OF OCCURRENCE = 110. M
CRITICAL TEN-METRE WINDSPEED = 4.0 M/S

MAXIMUM PERMISSIBLE CONCENTRATION = 0.210 PPM AS A 1.00 HOUR AVERAGE

STACK NUMBER	EFFECTIVE STACK HEIGHT (M)	CONTRIBUTION TO OVERALL MAXIMUM (PPM)
1	13.	0.153
2	14.	0.172
3	15.	0.180

***** TALLER STACK(S) NECESSARY *****

STACK NUMBER	REQUIRED STACK HEIGHT (M)	EFFECTIVE STACK HEIGHT (M)	CONTRIBUTION TO OVERALL MAXIMUM (PPM)
1	18.1	20.	0.064
2	18.1	22.	0.069
3	18.1	23.	0.071

DISTANCE TO MAXIMUM = 174. M
CRITICAL TEN-METRE WINDSPEED = 3.0 M/S

INPUT DATA

PROGRAM: FLARES

LINE	COLUMNS	VARIABLE NAME	UNITS	FORMAT	PROGRAM SYMBOL
1	1 - 80	Identifier (80 letters maximum)	-	20A4	ID
2	1, 2	Number of flares (20 maximum)	-	I2	NFLARE
	3, 4	Number of distances with elevation differences (50 maximum)	-	I2	NX
	11 - 20	Ambient temperature	°C	F10.4	TA
	21 - 30	Averaging time	h	F10.4	AVTH
	31 - 40	Maximum Permissible Concentration	ppm	F10.4	STD
	41 - 50	Tree canopy height	m	F10.4	TREE
	51 - 60	Distance to tree canopy from the origin	m	F10.4	XTREE
3	1 - 10	Flare height	m	F10.1	HS
	11 - 20	Flare distance from origin	m	F10.1	XLOC
	21 - 30	Total gas flow to flare at 101.325 kpa and reference temperature	m^3/s	F10.4	QTTREF
	31 - 40	Reference temperature	°C	F10.1	TREF
4	1 - 10	Fraction methane	-	F10.4	FC1
	11 - 20	Fraction ethane	-	F10.4	FC2
	21 - 30	Fraction propane	-	F10.4	FC3
	31 - 40	Fraction butane	-	F10.4	FC4
	41 - 50	Fraction pentanes plus	-	F10.4	FC5
	51 - 60	Fraction hydrogen sulphide	-	F10.4	FH2S
2+NFLARE		same as line 3 for other flares			
3+NFLARE		same as line 4 for other flares			
4+NFLARE	1 - 10	Distance from origin	m	F10.0	X
	11 - 20	Elevation above flare base	m	F10.0	XE
3+NFLARE +NX		same as line 4+NFLARE for other distances			

Data set may be repeated as required

```
C  ALBERTA DEPARTMENT OF THE ENVIRONMENT, ENVIRONMENTAL PROTECTION SERVICES
C  PRESCRIBED METHOD FOR FLARE DESIGN - SEPTEMBER, 1978
C                  PROGRAM NAME:  FLARES
C
C  THE MAINLINE READS THE CONTROL DATA, FLARE PARAMETERS AND TOPOGRAPHIC
C  INFORMATION.  THE VALUES OR THEIR MEANINGS ARE DISPLAYED IMMEDIATELY.
C  THE MAINLINE THEN ROUTES THE DATA TO THE APPROPRIATE SUBROUTINES FOR
C  COMPUTATION OF THE OVERALL MAXIMUM GROUND-LEVEL OR TREE-TOP CONCENTRA-
C  TION AND RELATED QUANTITIES.  IF THIS MGLC IS GREATER THAN THE MAXIMUM
C  PERMISSIBLE CONCENTRATION, A SUBROUTINE IS CALLED TO DETERMINE THE
C  REQUIRED FLARE HEIGHT.  ALL SUBROUTINES USE  A NUMBER OF FUNCTIONS.
C  ALL CONSTANTS ARE ASSIGNED THEIR VALUES IN THE BLOCK DATA SUBPROGRAM.
C
C  SEARCHES USE INCREMENTS OF 'UINC' BETWEEN THE TEN-METRE WINDSPEEDS
C  SPECIFIED BY 'US' AND 'UF', AND, IN FLAT TERRAIN, USE LOGARITHMIC
C  INCREMENTS OF DISTANCE.  SUCH DISCRETIZATION MAY CAUSE SOME SMALL
C  DIFFERENCES IN RESULTS IF IDENTICAL SITUATIONS ARE APPROACHED
C  THROUGH DIFFERENT SECTIONS OF THE PROGRAM OR IF DIFFERENT INCREMENT
C  SIZES ARE USED.
C
0001          DIMENSION X(50),XE(50),ID(20),HS(20),FC1(20),FC2(20),FC3(20),FC4(2
             *0),FC5(20),Q(20),H(20),HCRIT(20),HEFF(20),UHS(20),CHI(20),CHIM(20)
             *,FH2S(20),CM(20),XLOC(20),HPCM(20),QTTREF(20),QREF(20),TREF(20)
0002          COMMON /ELINV/IYF2PI/LOOP/US,UF,UINC,ZA/RADLOS/FRAD
0003       10 READ(5,20,END=370) (ID(I),I=1,20)
0004       20 FORMAT(20A4)
0005          READ(5,30) NFLARE,NX,TA,AVTH,STD,TREE,XTREE
0006       30 FORMAT(I2,6X,5F10.4)
0007          DO 45 J=1,NFLARE
0008          READ(5,40) HS(J),XLOC(J),QTTREF(J),TREF(J)
0009       40 FORMAT(2F10.1,F10.4,F10.1)
0010          READ(5,41) FC1(J),FC2(J),FC3(J),FC4(J),FC5(J),FH2S(J)
0011       41 FORMAT(6F10.4)
0012          QREF(J)=QTTREF(J)*FH2S(J)
0013          HPCM(J)=(FC1(J)*34.+FC2(J)*61.1+FC3(J)*88.8+FC4(J)*116.2+FC5(J)*
             *138.2+FH2S(J)*62.2)
0014       45 CONTINUE
0015          IF(NX.EQ.0) GOTO 65
0016          DO 60 I=1,NX
0017          READ(5,70) X(I),XE(I)
0018       70 FORMAT(2F10.0)
0019       60 CONTINUE
0020       65 AVT=AVTH*3600.
0021          WRITE(6,90)
0022       90 FORMAT('1','ALBERTA DEPARTMENT OF THE ENVIRONMENT, PRESCRIBED METH
             *OD FOR FLARE DESIGN')
0023          WRITE(6,100) (ID(I),I=1,20)
0024      100 FORMAT('-',5X,20A4)
0025          DO 85 J=1,NFLARE
0026          WRITE(6,105)J,HS(J),QTTREF(J),TREF(J),FC1(J),FC2(J),FC3(J),FC4(J),
             *FC5(J),FH2S(J),XLOC(J),QREF(J),HPCM(J)
C  WRITE DATA FOR EACH FLARE
0027      105 FORMAT('-','PARAMETERS FOR FLARE',1X,I2/
             *'0',14X,'FLARE HEIGHT =',F8.1,2X,'M'/
             *' ',7X,'FLARE GAS FLOW RATE =',F8.4,2X,'M**3/S AT REFERENCE TEMPER
             *ATURE AND 101.325 KPA'/
             *' ',5X,'REFERENCE TEMPERATURE =',F8.1,2X,'C' /
             *' ',10X,'FRACTION METHANE =',F8.3/
             *' ',11X,'FRACTION ETHANE =',F8.3/
             *' ',10X,'FRACTION PROPANE =',F8.3/
             *' ',11X,'FRACTION BUTANE =',F8.3/
             *' ',4X,'FRACTION PENTANES PLUS =',F8.3/
             *' ','FRACTION HYDROGEN SULFHIDE =',F8.3/
             *' ',10X,'FLARE DISTANCE =',F8.0,2X,'M  FROM ORIGIN'/
             *' ',13X,'EMISSION RATE =',F8.4,2X,'M**3/S AT REFERENCE TEMPERATURE
             *  AND 101.325 KPA'/
             *' ',1X,'HEAT VALUE OF FLARE GASES =',F8.2,2X,'MJ/M**3 AT 15.6 C AN
             *D 101.325 KPA')
0028          IF(HPCM(J).LT.9.0) WRITE(6,535)
0029      535 FORMAT('0','**** HEAT VALUE OF FLARE GAS IS INSUFFICIENT FOR ADEQ
             *UATE COMBUSTION ****')
C  'FRAD' IS THE FRACTION OF THE HEAT OF COMBUSTION THAT IS LOST DUE
C  TO RADIATION FROM THE FLAME
```

```
0030                  QH(J)=HPCM(J)*QTTREF(J)*(15.6+273.16)/(TREF(J)+273.16)*239900.*(1.
                     *-FRAD)
0031                  Q(J)=FMCS(J)*QTTREF(J)*(TA+273.16)/(TREF(J)+273.16)
0032            85    CONTINUE
0033                  WRITE(6,315) TA
0034            315   FORMAT('1',3X,'AMBIENT TEMPERATURE =',F6.0,2X,'C')
0035            360   WRITE(6,160)TYPCPI
0036            160   FORMAT('1','DIFFUSION WITHIN A MIXING LAYER BENEATH AN ELEVATED IN
                     *VERSION'/' ','INVERSION BASE AT LEVEL OF HIGHEST PLUME CR',F6.0,2X
                     *,'M, WHICHEVER IS LOWER')
0037                  WRITE(6,181) US,UF,UINC
0038            181   FORMAT('0','TEN-METRE WINDSPEEDS BETWEEN',F5.1,1X,'AND',
                     *F5.1,1X,'M/S IN INCREMENTS OF',F5.1,1X,'M/S ARE EXAMINED')
0039                  IF(NX.EQ.0) GOTO 345
0040                  WRITE(6,310)
0041            310   FORMAT('0',5X,'DISTANCE FROM ORIGIN',10X,'ELEVATION ABOVE ORIGIN')
0042                  WRITE(6,320)
0043            320   FORMAT(' ',10X,'IN METRES',22X,'IN METRES'/)
0044                  DO 340 KX=1,NX
0045                  WRITE(6,330) X(KX),XE(KX)
0046            330   FORMAT(' ',9X,F8.0,24X,F8.0)
0047            340   CONTINUE
0048            345   IF(NX.EQ.0) WRITE(6,346)
0049            346   FORMAT('-','FLAT, ROUGH TERRAIN'/
                     *' ','(SEARCH IS PERFORMED USING EQUAL LOGARITHMIC INCREMENTS OF DI
                     *STANCE)')
0050                  IF(TREE.GT.0.) WRITE(6,170) TREE,XTREE
0051            170   FORMAT('-',2X,'HEIGHT OF TREE CANOPY =',F6.0,2X,'M'/
                     *' ','DISTANCE TO TREE CANOPY =',F6.0,2X,'M FROM ORIGIN')
0052                  IF(NX.GT.0) CALL HILMAX(QH,HS,Q,X,XE,NX,CHIMAX,XMAX,UCRIT,HCRIT,
                     *AVT,XLOC,NFLARE,CHIM,TREE,XTREE)
0053                  IF(NX.EQ.0) CALL FLAMAX(QH,HS,Q,CHIMAX,XMAX,UCRIT,HCRIT,AVT,XLOC,
                     *NFLARE,CHIM,TREE,XTREE)
0054                  IF(TREE.LE.0.) WRITE(6,400) CHIMAX,AVTH
0055            400   FORMAT('-','OVERALL MAXIMUM GROUND-LEVEL CONCENTRATION =',
                     *F6.3,2X,'PPM AS A',F5.2,1X,'HOUR AVERAGE')
0056                  IF(TREE.GT.0.) WRITE(6,405) CHIMAX,AVTH
0057            405   FORMAT('-',5X,'OVERALL MAXIMUM TREETOP CONCENTRATION =',
                     *F6.3,2X,'PPM AS A',F5.2,1X,'HOUR AVERAGE')
0058                  WRITE(6,410) XMAX
0059            410   FORMAT(' ',20X,'DISTANCE OF OCCURRENCE =',F8.0,2X,'M')
0060                  WRITE(6,430) UCRIT
0061            430   FORMAT(' ',14X,'CRITICAL TEN-METRE WINDSPEED =',F8.1,2X,'M/S')
0062                  IF(XMAX.LT.XTREE) WRITE(6,435)
0063            435   FORMAT('0',' *** NOTE - THE MAXIMUM ACTUALLY OCCURS AT GROUND-LEVEL
                     * BETWEEN THE ORIGIN AND THE TREES ***')
0064                  WRITE(6,414) STD,AVTH
0065            414   FORMAT('-','MAXIMUM PERMISSIBLE CONCENTRATION =',F6.3,1X,'PPM AS A
                     *',F5.2,1X,'HOUR AVERAGE')
0066                  WRITE(6,415)
0067            415   FORMAT('0','FLARE',6X,'EFFECTIVE FLARE',5X,'CONTRIBUTION TO OVERAL
                     *L MAXIMUM',5X,'HEIGHT (M)',10X,'MAXIMUM (PPM)'/)
0068                  DO 420 J=1,NFLARE
0069                  WRITE(6,416) J,HCRIT(J),CHIM(J)
0070            416   FORMAT(' ',I2,10X,F8.0,17X,F8.3)
0071            420   CONTINUE
0072                  IF(CHIMAX.GT.STD) CALL REQHS(QH,HS,Q,X,XE,NX,STD,AVT,TREE,XTREE,
                     *XLOC,NFLARE)
0073                  GOTO 65
0074                  IF(NX.GT.0) NX=0
0075                  IF(NX.GT.0) GOTO 65
0076                  GOTO 10
0077            370   STOP
0078                  END
```

```
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                C
                C  THE FUNCTION 'RISE' GIVES THE PLUME RISE DUE TO BUOYANCY ACCORDING
                C  TO THE FINAL RISE FORMULA OF BRIGGS(1970)
                C
0001                FUNCTION RISE(QH,UHS)
0002                COMMON /BRIGGS/C1,G
0003                F=0.000037*QH
0004                IF(F.LE.55.) XSTAR=14.*F**0.625
0005                IF(F.GT.55.) XSTAR=34.*F**0.4
0006                XFR=3.5*XSTAR
0007                RISE=C1*F**(1./3.)*XFR**(2./3.)/UHS
0008                RETURN
0009                END
```

```
C
C  THE FUNCTION 'POTFLO' GIVES THE HEIGHT OF A PLUME ABOVE A CIRCULAR
C  CYLINDER OF INFINITE CROSSWIND EXTENT WITH RADIUS EQUAL TO THE LOCAL
C  ELEVATION OF THE TERRAIN ABOVE FLARE BASE
C
0001       FUNCTION POTFLO(HT,H)
0002       IF(HT.LE.0.0) GOTO 20
0003       POTFLO=H/2.-HT+0.5*SQRT(H*H+4.*HT*HT)
0004       RETURN
0005    20 POTFLO=H
0006       RETURN
0007       END
```

```
C
C  THE SUBROUTINE 'HILMAX' COMPUTES THE OVERALL MAXIMUM GROUND-LEVEL OR
C  TREE-TOP CONCENTRATION FOR COMPLEX TERRAIN WHERE THE DISTANCES AND
C  LOCAL ELEVATION DIFFERENCES HAVE BEEN SPECIFIED
C
0001          SUBROUTINE HILMAX(QH,HS,Q,X,XE,NX,CHIMAX,XMAX,UCRIT,HCRIT,AVT,XLOC
             *,NFLARE,CHIM,TREE,XTREE)
0002           DIMENSION XE(50),X(50),QH(20),HS(20),Q(20),H(20),UHS(20),XLOC(20),
             *HEFF(20),HCRIT(20),CHI(20),CHIM(20)
0003           COMMON /ELIN7/TYP2PI/LOOP/US,UF,UINC,ZA
0004           U=US
0005           CHIMAX=0.0
0006           IUF=IFIX((UF-US)/UINC)+1
0007           DO 30 IU=1,IUF
0008           DO 15 J=1,NFLARE
0009           UHS(J)=WDSPD(U,HS(J),ZA)
0010           H(J)=HS(J)+RISE(QH(J),UHS(J))
0011    15     CONTINUE
0012           DO 20 KX=1,NX
0013           IF(X(KX).LT.XTREE) XET=XE(KX)
0014           IF(X(KX).GE.XTREE) XET=XE(KX) + TREE
0015           HMAX=0.0
0016           DO 25 J=1,NFLARE
0017           HEFF(J)=POTFLO(XET,H(J))
0018           IF(HEFF(J).LE.HMAX) GOTO 25
0019           HMAX=HEFF(J)
0020    25     CONTINUE
C  THE PRECEDING LOOP CHOOSES THE LEVEL OF THE HIGHEST PLUME.  THE MIXING
C  LAYER DEPTH IS THEN SET EQUAL TO THIS OR TO THE VALUE CONTAINED IN
C  'TYP2PI', WHICHEVER IS LARGER.
0021           DML=AMAX1(HMAX,TYP2PI)
0022           CONCN=0.0
0023           DO 26 J=1,NFLARE
0024           XREL=X(KX)-XLOC(J)
0025           IF(XREL.LE.0.) CHI(J)=0.0
0026           IF(XREL.LE.0.) GOTO 26
C  THE VARIABLE 'DZ' IS THE VERTICAL SPREAD ENHANCEMENT FACTOR WHICH IS
C  SET EQUAL TO THE RECIPROCAL OF THE STREAMTUBE CONTRACTION DUE TO THE
C  PRESENCE OF THE ELEVATED TERRAIN ALONE
0027           IF(XE(KX).GT.0.) DZ=1.+(XE(KX)*XE(KX))/(HEFF(J)+XE(KX))**2.
0028           IF(XE(KX).LE.0.) DZ=1.
0029           CHI(J)=(1./DZ)*TRAP(Q(J),UHS(J),XREL,HEFF(J),DML,AVT)
0030           CONCN=CONCN+CHI(J)
0031    26     CONTINUE
0032           IF(CONCN.LE.CHIMAX) GOTO 20
0033           CHIMAX=CONCN
0034           XMAX=X(KX)
0035           UCRIT=U
0036           DO 40 J=1,NFLARE
0037           CHIM(J)=CHI(J)
0038    40     HCRIT(J)=HEFF(J)
0039    20     CONTINUE
0040           U=U+UINC
0041    30     CONTINUE
0042           RETURN
0043           END
```

```
                C
                C  THE FUNCTION 'TRAP' GIVES THE GROUND-LEVEL OR TREE-TOP CONCENTRATION
                C  DUE TO PLUME TRAPPING USING THE GAUSSIAN PLUME FORMULA WITH TEN
                C  REFLECTIONS BETWEEN THE SURFACE AND THE ELEVATED INVERSION
                C
0001                FUNCTION TRAP(Q,UHS,X,H,DML,AVT)
0002                COMMON /PLUM/PY,PZ,SIGZR,XREF,SIGYR,PT
0003                SIGMAZ=SIGZR*(X/XREF)**PZ
0004                SIGMAY=SIGYR*(X/XREF)**PY
0005                SIGMAY=SIGMAY*(AVT/180.)**PT
                C  THE PRECEDING LINE IS THE AVERAGING TIME CORRECTION.  IT IS APPLIED
                C  TO THE CROSSWIND PLUME SPREAD ONLY.
0006                SUM=0.0
0007                DO 10 N=1,10
0008                S1=(-H-2.*FLOAT(N)*DML)/SIGMAZ
0009                S2=(H-2.*FLOAT(N)*DML)/SIGMAZ
0010                IF(ABS(S1).GT.10.0) S1=10.0
0011                IF(ABS(S2).GT.10.0) S2=10.0
0012                SUM=SUM+2.*EXP(-0.5*S1*S1) + 2.*EXP(-0.5*S2*S2)
0013             10 CONTINUE
0014                S3=H/SIGMAZ
0015                IF(ABS(S3).GT.10.) S3=10.
0016                F1=Q*1000000./(6.*3.14159*UHS*SIGMAZ*SIGMAY)
0017                F2=2.*EXP(-0.5*S3*S3) + SUM
0018                TRAP=F1*F2
0019                RETURN
0020                END
```

```
C
C  THE BLOCK DATA SUBPROGRAM ASSIGNS VALUES TO ALL CONSTANTS AND SOME
C  CONTROL VARIABLES FOR USE THROUGHOUT THE PROGRAM
C
0001        BLOCK DATA
0002        COMMON /PLAW/PY,PZ,SIGZR,XREF,SIGYR,PT/ELINV/TYP2PI/BRIGGS/C1,G
           */LOSP/US,UF,UINC,ZA/WIND/PW/DIST/STPLOG/RADLOS/FRAD
0003        DATA SIGZR/50./,XREF/1000./,PZ/0.65/,SIGYR/85./,PY/0.88/,C1/1.2/,
           *G/9.8/,TYP2PI/100./,US/1./,UF/20./,ZA/10./,PW/0.3/,PT/0.2/,
           *UINC/0.5/,STPLOG/0.04/,FRAD/0.25/
0004        END
```

```
C
C  SUBROUTINE 'FLAMAX' COMPUTES THE OVERALL MAXIMUM GROUND-LEVEL OR
C  TREE-TOP CONCENTRATION FOR FLAT TERRAIN BY SEARCHING THROUGH
C  THE SPECIFIED WIND SPEEDS AND THE APPROPRIATE DISTANCES.  THE
C  DISTANCE SEARCH USES LOGARITHMIC DISTANCE INCREMENTS SPECIFIED BY
C  THE CONTROL PARAMETER 'STPLCS'.  THIS ALLOWS FOR VARIABLE RESOLUTION,
C  FINE AT SHORT RANGES, PROGRESSIVELY COARSER AT LONGER RANGES WHERE
C  THE CONCENTRATIONS ARE NOT AS SENSITIVE TO DISTANCE.  SEARCH TIME
C  IS FAR LESS THAN WOULD BE REQUIRED WITH FIXED DISTANCE INCREMENTS.
C
0001          SUBROUTINE FLAMAX(QH,HS,Q,CHIMAX,XMAX,UCRIT,HCRIT,AVT,XLOC,NFLARE,
             *CHIM,TREE,XTREE)
0002           DIMENSION QH(20),HS(20),Q(20),H(20),UHS(20),XLOC(20),HCRIT(20),
             *CHI(20),CHIM(20),HEFF(20)
0003           COMMON /ELIN/TYP2P1/PLAW/PY,PZ,SIGZR,XREF,SIGYR,PT/LOOP/US,UF,
             *UINC,ZA/DIST/STPLCS
0004           CALL LIMIT(HS,IXS,IXF,NFLARE,QH,TREE,XLOC)
0005           U=US
0006           CHIMAX=0.0
0007           IUF=IFIX((UF-US)/UINC)+1
0008           DO 30 IU=1,IUF
0009           DO 15 J=1,NFLARE
0010           UHS(J)=WDSPD(U,HS(J),ZA)
0011           H(J)=HS(J)+RISE(QH(J),UHS(J))
0012    15     CONTINUE
0013           DO 20 IX=IXS,IXF
0014           X=10.**(1. + STPLOG*FLOAT(IX))
0015           HMAX=0.0
0016           DO 25 J=1,NFLARE
0017           IF(X.LT.XTREE) HEFF(J)=H(J)
0018           IF(X.GE.XTREE) HEFF(J)=FOTFLO(TREE,H(J))
C  THE PRECEDING LINE IS THE PLUME HEIGHT CORRECTION FOR THE PRESENCE
C  OF A TREE CANOPY.
0019           IF(HEFF(J).LE.HMAX) GOTO 25
0020           HMAX=HEFF(J)
0021    25     CONTINUE
0022           DML=AMAX1(HMAX,TYP2P1)
0023           CONCN=0.0
0024           DO 26 J=1,NFLARE
0025           XREL=X-XLOC(J)
0026           IF(XREL.LE.0.) CHI(J)=0.0
0027           IF(XREL.LE.0.) GOTO 26
0028           CHI(J)=TRAP(Q(J),UHS(J),XREL,HEFF(J),DML,AVT)
0029           CONCN=CONCN+CHI(J)
0030    26     CONTINUE
0031           IF(CONCN.LE.CHIMAX) GOTO 20
0032           CHIMAX=CONCN
0033           XMAX=X
0034           UCRIT=U
0035           DO 40 J=1,NFLARE
0036           CHIM(J)=CHI(J)
0037    40     HCRIT(J)=HEFF(J)
0038    20     CONTINUE
0039           U=U+UINC
0040    30     CONTINUE
0041           RETURN
0042           END
```

```
C
C  THE SUBROUTINE 'REQHS' CALCULATES THE FLARE HEIGHT(S) NEEDED TO KEEP
C  THE OVERALL MAXIMUM GROUND-LEVEL CONCENTRATION AT OR BELOW THE MAXIMUM
C  PERMISSIBLE CONCENTRATION.  FOR FLARES LESS THAN 30.0 M HIGH INCREMENTS
C  OF 1.0 M ARE USED; FOR FLARES GREATER THAN OR EQUAL TO 30.0 M HIGH
C  INCREMENTS OF 3.0 M ARE USED.  ALL FLARES IN THE CALCULATION ARE
C  INCREMENTED BY THE SAME AMOUNT.
C
0001        SUBROUTINE REQHS(QH,HS,Q,X,XE,NX,STD,AVT,TREE,XTREE,XLOC,NFLARE)
0002        DIMENSION X(50),XE(50),HS(20),D(20),VS(20),TG(20),Q(20),HCRIT(20)
           *,CHIM(20),HSRQ(20),XLOC(20)
0003        DO 5 I=1,NFLARE
0004      5 HSRQ(I)=HS(I)
0005     10 DO 15 J=1,NFLARE
0006        IF(HSRQ(J).LT.30.) HSINC=1.
0007        IF(HSRQ(J).GE.30.) HSINC=3.
0008        HSRQ(J)=HSRQ(J)+HSINC
0009     15 CONTINUE
0010        IF(NX.EQ.0) CALL FLAMAX(QH,HSRQ,Q,CHIMAX,XMAX,UCRIT,HCRIT,AVT,XLOC
           *,NFLARE,CHIM,TREE,XTREE)
0011        IF(NX.GT.0) CALL HILMAX(QH,HSRQ,Q,X,XE,NX,CHIMAX,XMAX,UCRIT,HCRIT,
           *AVT,XLOC,NFLARE,CHIM,TREE,XTREE)
0012        IF(CHIMAX.GT.STD) GOTO 10
0013        WRITE(6,21)
0014     21 FORMAT('-'/'-','***** TALLER FLARE(S) NECESSARY *****')
0015        WRITE(6,30)
0016     30 FORMAT('-','FLARE',6X,'REQUIRED FLARE',5X,'EFFECTIVE FLARE',5X,'CO
           *N)RIBUTION TO OVERALL'/' ','NUMBER',5X,'HEIGHT (M)',10X,'HEIGHT (M
           *)',10X,'MAXIMUM (FFM)'/)
0017        DO 35 J=1,NFLARE
0018        WRITE(6,31) J,HSRQ(J),HCRIT(J),CHIM(J)
0019     31 FORMAT(' ',I2,12X,F8.0,10X,F8.0,17X,F8.3)
0020     35 CONTINUE
0021        WRITE(6,40) XMAX
0022     40 FORMAT('0',12X,'DISTANCE TO MAXIMUM =',F8.0,2X,'M')
0023        WRITE(6,50) UCRIT
0024     50 FORMAT(' ',3X,'CRITICAL TEN-METRE WINDSPEED =',F8.1,2X,'M/S')
0025        RETURN
0026        END
```

```
C
CC  THE FUNCTION 'WDSPD' GIVES THE WINDSPEED AT ANY HEIGHT USING A SIMPLE
CC  POWER LAW AND THE WINDSPEED AT ANOTHER HEIGHT
C
0001        FUNCTION WDSPD(U1,Z2,Z1)
0002        COMMON /WIND/PW
0003        WDSPD=U1*(Z2/Z1)**PW
0004        RETURN
0005        END
```

```
C
C  THE SUBROUTINE 'LIMIT' DETERMINES THE LARGEST AND SMALLEST DISTANCES
C  BETWEEN WHICH THE FLAT TERRAIN OVERALL MAXIMUM GROUND-LEVEL CONCENTRA-
C  TION MUST LIE.  THIS RESTRICTS THE SEARCH AND SAVES ON COMPUTER TIME.
C
      SUBROUTINE LIMIT(HS,IXS,IXF,NFLARE,GH,TREE,XLOC)
      COMMON /PLAN/PY,PZ,SIGZR,XREF,SIGYR,PT/DIST/STPLOG/LOOP/US,UF,
     *UINC,ZA
      DIMENSION GH(20),HS(20),H(20),XLOC(20)
      HMIN=999999.
      DO 10 J=1,NFLARE
      UFHS=WDSPD(UF,HS(J),ZA)
      H(J)=HS(J)+RISE(GH(J),UFHS)
      H(J)=POTFLO(TREE,H(J))
      IF(H(J).GE.HMIN) GOTO 10
      HMIN=H(J)
   10 CONTINUE
      HMAX=0.0
      DO 20 J=1,NFLARE
      USHS=WDSPD(US,HS(J),ZA)
      H(J)=HS(J)+RISE(GH(J),USHS)
      IF(H(J).LE.HMAX) GOTO 20
      HMAX=H(J)
   20 CONTINUE
      XLOCX=0.0
      DO 30 J=1,NFLARE
      IF(XLOC(J).LE.XLOCX) GOTO 30
      XLOCX=XLOC(J)
   30 CONTINUE
      XS=((PZ*HMIN*HMIN)/((PY+PZ)*(SIGZR/XREF**PZ)**2.))**(1./(2.*PZ))
      IXSMN=IFIX((ALOG10(XS)-1.0)/STPLOG)
      IXS=AMAX0(IXSMN,1)
      XF=((PZ*HMAX*HMAX)/((PY+PZ)*(SIGZR/XREF**PZ)**2.))**(1./(2.*PZ))+
     *XLOCX
      IXFMX=IFIX((ALOG10(XF)-1.0)/STPLOG+0.5)
      IMAX=IFIX(4./STPLOG)
      IXF=AMIN0(IXFMX,IMAX)
      RETURN
      END
```

ALBERTA DEPARTMENT OF THE ENVIRONMENT, PRESCRIBED METHOD FOR FLARE DESIGN

SMALL PLANT FLARING SOUR GAS

PARAMETERS FOR FLARE 1

FLARE HEIGHT	=	50.0	M
FLARE GAS FLOW RATE	=	0.2500	M**3/S AT REFERENCE TEMPERATURE AND 101.325 KPA
REFERENCE TEMPERATURE	=	21.0	C
FRACTION METHANE	=	0.200	
FRACTION ETHANE	=	0.050	
FRACTION PROPANE	=	0.010	
FRACTION BUTANE	=	0.010	
FRACTION PENTANES PLUS	=	0.010	
FRACTION HYDROGEN SULPHIDE	=	0.200	
FLARE DISTANCE	=	0.	M FROM ORIGIN
EMISSION RATE	=	0.0500	M**3/S AT REFERENCE TEMPERATURE AND 101.325 KPA
HEAT VALUE OF FLARE GASES	=	17.73	MJ/M**3 AT 15.6 C AND 101.325 KPA

AMBIENT TEMPERATURE = 21. C

DIFFUSION WITHIN A MIXING LAYER BENEATH AN ELEVATED INVERSION
INVERSION BASE AT LEVEL OF HIGHEST PLUME OR 100. M, WHICHEVER IS LARGER

TEN-METRE WINDSPEEDS BETWEEN 1.0 AND 20.0 M/S IN INCREMENTS OF 0.5 M/S ARE EXAMINED

DISTANCE FROM ORIGIN IN METRES	ELEVATION ABOVE ORIGIN IN METRES
500.	3.
1000.	7.
1500.	15.
2000.	30.
2500.	45.
3000.	45.
3500.	60.
4000.	75.
4500.	90.
5000.	105.

HEIGHT OF TREE CANOPY = 20. M
DISTANCE TO TREE CANOPY = 100. M FROM ORIGIN

OVERALL MAXIMUM TREETOP CONCENTRATION = 0.288 PPM AS A 0.50 HOUR AVERAGE
DISTANCE OF OCCURRENCE = 2000. M
CRITICAL TEN-METRE WINDSPEED = 1.5 M/S

MAXIMUM PERMISSIBLE CONCENTRATION = 0.200 PPM AS A 0.50 HOUR AVERAGE

FLARE NUMBER	EFFECTIVE FLARE HEIGHT (M)	CONTRIBUTION TO OVERALL MAXIMUM (PPM)
1	99.	0.288

***** TALLER FLARE(S) NECESSARY *****

FLARE NUMBER	REQUIRED FLARE HEIGHT (M)	EFFECTIVE FLARE HEIGHT (M)	CONTRIBUTION TO OVERALL MAXIMUM (PPM)
1	80.	116.	0.191

DISTANCE TO MAXIMUM = 2000. M
CRITICAL TEN-METRE WINDSPEED = 1.5 M/S

ALBERTA DEPARTMENT OF THE ENVIRONMENT, PRESCRIBED METHOD FOR FLARE DESIGN

SMALL PLANT FLARING SOUR GAS

PARAMETERS FOR FLARE 1

FLARE HEIGHT =	50.0	M
FLARE GAS FLOW RATE =	0.5500	M**3/S AT REFERENCE TEMPERATURE AND 101.325 KPA
REFERENCE TEMPERATURE =	21.0	C
FRACTION METHANE =	0.200	
FRACTION ETHANE =	0.050	
FRACTION PROPANE =	0.010	
FRACTION BUTANE =	0.010	
FRACTION PENTANES PLUS =	0.010	
FRACTION HYDROGEN SULPHIDE =	0.200	
FLARE DISTANCE =	0.	M FROM ORIGIN
EMISSION RATE =	0.0500	M**3/S AT REFERENCE TEMPERATURE AND 101.325 KPA
HEAT VALUE OF FLARE GASES =	17.73	MJ/M**3 AT 15.6 C AND 101.325 KPA

AMBIENT TEMPERATURE = 21. C

DIFFUSION WITHIN A MIXING LAYER BENEATH AN ELEVATED INVERSION
INVERSION BASE AT LEVEL OF HIGHEST PLUME OR 100. M, WHICHEVER IS LARGER

TEN-METRE WINDSPEEDS BETWEEN 1.0 AND 20.0 M/S IN INCREMENTS OF 0.5 M/S ARE EXAMINED

FLAT, ROUGH TERRAIN
(SEARCH IS PERFORMED USING EQUAL LOGARITHMIC INCREMENTS OF DISTANCE)

HEIGHT OF TREE CANOPY = 20. M
DISTANCE TO TREE CANOPY = 100. M FROM ORIGIN

OVERALL MAXIMUM TREETOP CONCENTRATION = 0.245 PPM AS A 0.50 HOUR AVERAGE
DISTANCE OF OCCURRENCE = 1445. M
CRITICAL TEN-METRE WINDSPEED = 2.0 M/S

MAXIMUM PERMISSIBLE CONCENTRATION = 0.200 PPM AS A 0.50 HOUR AVERAGE

FLARE NUMBER	EFFECTIVE FLARE HEIGHT (M)	CONTRIBUTION TO OVERALL MAXIMUM (PPM)
1	95.	0.245

***** TALLER FLARE(S) NECESSARY *****

FLARE NUMBER	REQUIRED FLARE HEIGHT (M)	EFFECTIVE FLARE HEIGHT (M)	CONTRIBUTION TO OVERALL MAXIMUM (PPM)
1	68.	107.	0.189

DISTANCE TO MAXIMUM = 1738. M
CRITICAL TEN-METRE WINDSPEED = 2.0 M/S

3.5 ALTERNATIVE METHODS

Techniques other than the Prescribed Calculation Method may be used for stack design provided that:

1. their site-specific applicability is demonstrated, and
2. a detailed air quality impact assessment is presented.

Alternative techniques will probably involve an attempt to model more realistically the atmospheric processes governing the dispersion of stack effluent. To date no general standards of model performance or uniform validation procedures have been established, although the need for these has been clearly identified in the scientific community. Also, verification must be distinguished from calibration. The latter is the process of applying a corrective factor for systematic errors or of adjusting empirical constants or values which have not been measured. Verification refers to the testing and confirmation of individual model elements (relationships and submodels) on the basis that the whole can be no better than the weakest component.

As Pasquill has poetically summarized:

> Calibration may be consoling
> But is a practice we shouldn't condone
> And for validation to have virtue
> The physics and chemistry must be known.

Model validation can be a very costly enterprise. The potential benefits must be weighed carefully before proceeding with any field verification program.

The issue is further complicated by the fact that some models, by nature, are not verifiable as a practical matter. In such cases, a

calibration is all that can be accomplished. Alberta Environment will accept calibrated models under the conditions that:

1. All assumptions, approximations, empirical constants, physical variables, computational conveniences and other pertinent features are clearly identified.

2. All relationships and formulations are supported by scientific evidence drawn from the open literature.

3. The sensitivity of the model to input parameter variations is well documented.

4. The model has been tested with at least one of the more complete data sets available in the world and has been found to give satisfactory results.

The site specific accuracy of the model must then be established by comparing predicted and observed values both in intermediate parameters and in pollutant concentrations. Agreement should be presented graphically in a scatter plot and measured by means of some appropriate statistic such as mean error, maximum error, mean error relative to the variance of the observations, skill score, contingency table, correlation coefficient, variance about a one-to-one correspondence relative to the variance of the observations, Wilcoxon Rank test, or Spearman's Rank correlation. In some instances it may be useful to compare predicted and observed patterns, although it is difficult to quantify such agreement.

The extent of field measurements necessary for adequate evaluation and/or calibration of a proposed model will vary with the complexity of the model. In general, the field data should be gathered

under typical weather conditions in each season of the year, and all input variables must be measured directly or indirectly. These intensive field studies must be related to the long-term normals for the area. The normals for some variables may have to be synthesized in some manner.

Once the model has been evaluated and/or calibrated, it should be used to enumerate the expected concentrations in each of the appropriate weather categories. The maximum concentration occurring anywhere at ground level should be tabulated along with its expected frequency of occurrence and probable error. In addition, the concentrations occurring at sensitive receptor points should be calculated and the frequency of occurrence indicated. The largest concentration in the list should be identified.

Alberta Environment sometimes uses a generalized Gaussian plume model for flat terrain in the above manner. For the convenience of those who do not have access to similar models, a listing and a description of this model, called PLUMES, appears in the Appendix.

Ideally, models should be used to produce the expected frequency distribution of concentrations at the sensitive receptors. These distributions are likely to be exponential in rural areas and log-normal in urban areas. Goodness-of-fit tests would then be applied to determine the most appropriate probability distribution function. This function can then be used to estimate the frequency of concentrations in excess of the maximum permissible concentration. Long-term continuous air monitoring data are an invaluable source of data for

verification. It would also be useful to generate the frequency distribution of the spatial maximum concentration. An estimate of the frequency of ground level concentrations in excess of the maximum permissible concentrations anywhere in the vicinity of the stack would be the ultimate statistic of interest.

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APPENDIX

A Gaussian plume model for use in an alternative method of stack design.

A.1 UNLIMITED MIXING

For a homogeneous atmosphere, the concentration at a point (x,y,z) due to a plume at a height H is given by:

$$\chi(x,y,z : H) = \frac{Q}{2\pi\sigma_y\sigma_z u}\left[\exp -\frac{1}{2}\left(\frac{y}{\sigma_y}\right)^2\right]\left[\exp -\frac{1}{2}\left(\frac{z-H}{\sigma_z}\right)^2 + \exp -\frac{1}{2}\left(\frac{z+H}{\sigma_z}\right)^2\right]$$

where Q is the emission rate in m^3/s.

u is the wind speed in m/s.

χ is the concentration in ppm.

σ_y, σ_z are the lateral and vertical plume spreads, respectively.

A.2 LIMITED MIXING (PLUME TRAPPING)

For a heterogeneous atmosphere where this is an impermeable inversion with base at height L, the concentration at a point (x,y,z) due to a plume at height H is given by: (Bierly and Hewson, 1962)

$$\chi(x,y,z\ ;\ H) = \frac{Q}{2\pi\sigma_y\sigma_z\ u}\left[\exp\ -\frac{1}{2}\left(\frac{y}{\sigma_y}\right)^2\right]\left\{\exp\ -\frac{1}{2}\left(\frac{z-H}{\sigma_z}\right)^2\right.$$

$$+\ \exp\ -\frac{1}{2}\left(\frac{z+H}{\sigma_z}\right)^2$$

$$+\ \sum_{n=1}^{n=N}\left[\exp\ -\frac{1}{2}\left(\frac{z-H-2nL}{\sigma_z}\right)^2\right.$$

$$+\ \exp\ -\frac{1}{2}\left(\frac{z+H-2nL}{\sigma_z}\right)^2$$

$$+\ \exp\ -\frac{1}{2}\left(\frac{z-H+2nL}{\sigma_z}\right)^2$$

$$\left.\left.+\ \exp\ -\frac{1}{2}\left(\frac{z+H+2nL}{\sigma_z}\right)^2\right]\right\}$$

If the plume height calculated for the mixing layer conditions is less than or equal to the inversion base height ($H < L$) the calculation is straight forward.

If the plume height calculated for the conditions within the mixing layer exceeds the inversion base height ($H > L$) then a decision must be made as to whether or not the plume is trapped. To do this, the

plume height for the conditions within the trapping inversion is calculated. (HMIN in the program). If this height is less than or equal to the inversion base height (HMIN $\leq$ L) the plume is considered trapped at the height of the inversion base L. If this height exceeds the inversion base height (HMIN > L) the plume is considered to be embedded in the inversion at that height. It is subsequently allowed to diffuse at the rate given by the Pasquill E category.

A.3 INVERSION BREAKUP FUMIGATION

For the transient condition of a Hewson fumigation, the maximum concentration, assumed uniform in the layer, is given by:

$$\chi(x,y,z : H) = \frac{Q}{\sqrt{2\pi}\, u\, \sigma_{yf}\, H_i} \exp -\frac{1}{2}\left(\frac{y}{\sigma_{yf}}\right)^2$$

where $H_i = H + 2.15\sigma_z$

$\sigma_{yf} = \sigma_y + 0.47H$

σ_z is the vertical spread in the stable air.

σ_y is the lateral spread in the stable air.

H_i allows for the whole plume to be mixed downwards and σ_{yf} allows for the additional spreading of the plume during the downward mixing.

The relationship for σ_{yf} is given by TVA (1970) and differs markedly from that given by Turner (1970).

The nearest downwind distance that can be considered for a fumigation must be great enough, based on the time required to eliminate the inversion, that the portion of the plume was initially emitted into stable air. This distance is given by:

$$x = u_s t_m$$

where u_s is the mean wind in the stable layer.

t_m is the time required to eliminate the inversion from h_s the physical height of the stack to H_i.

The time t_m is given by:

$$t_m = \frac{H_i^2 - h_s^2}{4K}$$

where K is the eddy diffusivity for heat.

This equation was suggested by Hewson (1945) based on an equation of Taylor (1915). Hewson suggested a value of K = 3 m^2/s. However, TVA (1970) found values of K ranging from 2 m^2/s to 40 m^2/s with a mean of 20 m^2/s. In this program, a value of 10 m^2/s has been arbitrarily chosen as representing the correct order of magnitude.

A.4 PLUME RISE

According to Briggs (1969) the rise of a buoyant plume close to the stack is given by:

$$h_r = c_1 F^{1/3} x^{2/3} u^{-1}$$

where c_1 is a dimensionless constant.

x is downwind distance.

u is the wind speed at stack height.

F is the buoyancy flux defined by:

$$F = r^2 v_s g \frac{T_g - T_a}{T_g}$$

where r is the stack radius.

u_s is the stack exit speed.

T_g is the stack gas exit temperature.

T_a is average ambient temperature.

g is the acceleration due to gravity.

After some distance the slope of the plume axis with the horizontal becomes so small that for all practical purposes the plume can be assumed at an equilibrium height. Briggs (1970) showed that for a neutral or unstable atmosphere this distance is about $3.5x^*$ where x^* is given by:

$$x^* = 14F^{5/8} \quad \text{for} \quad F \leq 55 \text{ m}^4\text{s}^{-3}$$

$$x^* = 34F^{2/5} \quad \text{for} \quad F > 55 \text{ m}^4\text{s}^{-3}$$

For a stable atmosphere the plume levels off at a height of:

$$h_r = c_2 \left(\frac{F}{u_s}\right)^{1/3}$$

where c_2 is a dimensionless constant.

S is the restoring acceleration per unit vertical displacement for adiabatic motion in the atmosphere, defined by:

$$s = \frac{g}{T} \frac{\partial \theta}{\partial z}$$

where $\frac{\partial \theta}{\partial z}$ is the vertical gradient of potential temperature.

Briggs (1975) recommended that $c_1 = 1.6$, $c_2 = 2.6$.

According to Briggs (1969) the rise of a pure momentum jet is given by:

$$h_r = c_3 \, F_m^{1/3} \, x^{1/3} \, u^{-2/3}$$

where c_1 is a dimensionless constant.

F_m is the momentum flux, defined by:

$$F_m = v_s^2 \, r^2 \, \frac{T_a}{T_g}$$

This is valid in neutral and unstable conditions up to the point where:

$$h_r = 6 \, \frac{v_s}{u} \, r$$

which is taken as the final rise.

In stable conditions the momentum jet levels out at:

$$h_r = c_4 \left(\frac{F_m}{u}\right)^{1/3} s^{-1/6}$$

where c_4 is a dimensionless constant.

Briggs (1969) gave $c_4 = 1.5$ and implied a value $c_3 = 2.3$.

In the program PLUMES, both the momentum rise and buoyancy rise are calculated and the larger of the two used in determining the plume height for subsequent computations.

A.5 STACK AERODYNAMIC DOWNWASH

The wind tunnel observations of Sherlock and Stalker (1941) showed that downwash occurs when $v_s/u < 1.5$ and that the plume is brought down about one stack diameter for $v_s/u = 1$. Accordingly, Briggs (1973) suggested that the plume rise should be corrected by means of the formula:

$$h_s' = h_s + 2\left(\frac{v_s}{u} - 1.5\right) D$$

where D is the radius of the stack exit.

In PLUMES if the exit speed is less than one and one-half times the wind speed at stack height the message "stack aerodynamic downwash occurs under the specified conditions" is printed and the effective stack height is reduced in accordance with this formula.

A.6 PLUME SPREADS

F. B. Smith (Pasquill, 1974) derived a family of vertical plume spread curves allowing for the effect of surface roughness. Table A1 provides information for choosing the appropriate roughness. These were approximated by power laws. In the program PLUMES they are given by:

$$\sigma_z = \sigma_{z\ \mathrm{ref}} \left(\frac{x}{x_{\mathrm{ref}}}\right)^{p_z}$$

with the constants shown in Table A2.

Smith did not give any values for the effect of surface roughness on lateral plume spreads. In the literature it is often found that increased roughness is equivalent to about half a stability category change towards the unstable. The program PLUMES does this by using a factor of 1.2 to get lateral spreads for 100 cm roughness from values for 10 cm roughness and a factor of 0.8 for 1 cm roughness. The 10 cm lateral spread values are given by:

$$\sigma_y = \sigma_{y\ \mathrm{ref}} \left(\frac{x}{x_{\mathrm{ref}}}\right)^{p_y}$$

with the constants given in Table A3 (based on South West Energy Task Force, 1972).

A.7 WIND SPEEDS

Wind speed u_2 at any height z_2 is determined from the wind speed u_1 at another height z_1 by means of the simple power law:

$$u_2 = u_1 \left(\frac{z_2}{z_1}\right)^{P_u}$$

Values of the exponent are a function of stability and roughness as given in Table A4.

Plume rise calculations use the wind speed calculated at stack height.

Diffusion calculations initially use the wind speed at plume height (source height or effective stack height).

The increase of wind speed with height constitutes a dispersion mechanism different from that described by the sigmas, and at longer distances it becomes significant. Smith and Singer (1966) introduced the concept of a "mean equivalent wind" to account for this phenomenon. They showed that the appropriate wind speed is the speed at a height of about $0.62\sigma_z$. In accordance with this result, the program PLUMES uses the wind speed at stack height until $h_s = 0.62\sigma_z$ and thereafter uses the wind speed at a height of $0.62\sigma_z$. In the case of fumigation or trapping, the appropriate height is limited to 0.62 times the height of the mixing layer.

Table A1 Surface features corresponding to each order of magnitude of the roughness length

Roughness length order of magnitude (cm)	Surface Features
1	flat and open with obstructions several centimetres in height e.g. prairie grassland, arctic tundra, cultivated fields, young agricultural crops
10	flat or gently rolling, covered by vegetation up to a few metres in height e.g. mature agricultural crops, with scattered obstructions of various sizes e.g. windbreaks, farm buildings
100	flat or rolling, covered with obstructions several tens of metres in height e.g. forests, cities

Table A2 Power law fit to the revised Pasquill-Smith vertical plume spread curves for roughness - 10 cm

Stability Category	σ_z ref in metres at x_{ref} = 1000 m			P_z		
	1 cm	10 cm	100 cm	1 cm	10 cm	100 cm
A	102	140	190	.94	.90	.83
B	62	80	110	.89	.85	.77
C	43	56	77	.85	.80	.72
D	29	38	50	.81	.76	.68
E	17	23	31	.78	.73	.65
F	9	12	17	.72	.67	.58

Table A3 Power law fit to Pasquill-Gifford lateral plume spread curves for roughness ~ 10 cm

Stability Category	σ_y ref in metres at x_{ref} = 1000 m	p_y
A	210	0.88
B	160	0.88
C	100	0.88
D	68	0.88
E	50	0.88
F	34	0.88

Table A4 Power law exponents as a function of stability and roughness (Irwin, 1979)

Stability Category	p_u		
	1 cm	10 cm	100 cm
A	0.05	0.08	0.17
B	0.06	0.09	0.17
C	0.06	0.11	0.20
D	0.12	0.16	0.27
E	0.34	0.32	0.38
F	0.53	0.54	0.61

INPUT DATA

PROGRAM: PLUMES

LINE	COLUMNS	VARIABLE NAME	UNITS	FORMAT	PROGRAM SYMBOL
1	1 - 80	Report title (80 letters maximum)	-	20A4	ITITLE
2	1 - 10	Wind speed	m/s	F10.2	WSPD
	11 - 20	Wind direction	degrees from true north	F10.2	WDIR
	21 - 30	Anemometer height	m	F10.2	ZA
	31 - 40	Ambient temperature	°C	F10.2	TA
3	1, 2	Pasquill stability category 01 = extremely unstable 02 = moderately unstable 03 = slightly unstable 04 = neutral 05 = slightly stable 06 = moderately stable	-	I2	IPSC
	3, 4	Roughness type 01 = roughness of 1 cm 02 = roughness of 10 cm 03 = roughness of 100 cm	-	I2	IRT
	5, 6	Mixing type 00 = unlimited 01 = limited for stability category 01-04 gives trapping for stability category 05-06 gives fumigation	-	I2	MT
	11 - 20	Temperature gradient in whole boundary layer for stable conditions in upper layer if plume trapping or fumigation occurs	°C/M	F10.3	DTDZ
	21 - 30	Mixing layer thickness	m	F10.3	DML
	31 - 40	Averaging time	h	F10.3	AVTH

. . . CONTINUED

INPUT DATA

PROGRAM: PLUMES

CONTINUED . . .

LINE	COLUMNS	VARIABLE NAME	UNITS	FORMAT	PROGRAM SYMBOL
4	1, 2	Number of stacks (50 maximum)	-	I2	NSTACK
	11 - 20	Maximum downwind distance	m	F10.0	DD2
	21 - 30	Minimum downwind distance	m	F10.0	DD1
	31 - 40	Downwind distance increment	m	F10.0	XINC
	41 - 50	Maximum crosswind distance (positive)	m	F10.0	DC2
	51 - 60	Minimum crosswind distance (negative)	m	F10.0	DC1
	61 - 70	Crosswind distance increment	m	F10.0	YINC
	71 - 80	Height of calculation plane (ground level is 0.0)	m	F10.0	ZPLANE
5	1 - 10	Stack height	m	F10.4	HSF
	11 - 20	Stack exit diameter	m	F10.4	DF
	21 - 30	Stack distance from origin	m	F10.4	DIS
	31 - 40	Stack direction from origin	degrees from true north	F10.4	STANG
	41 - 50	Stack gas exit speed	m/s	F10.4	VSF
	51 - 60	Stack gas exit temperature	°C	F10.4	TGF
	61 - 70	Pollutant emission rate at reference temperature and 101.325 kpa	m^3/s	F10.4	Q
	71 - 80	Reference temperature	°C	F10.4	TREF
6		additional input cards/lines identical to 5 for each stack to be considered			
	(Additional cards as required TOTAL = 4+NSTACK)		The program will process any number of these data sets.		

```
C  ALBERTA DEPARTMENT OF THE ENVIRONMENT, ENVIRONMENTAL PROTECTION SERVICES
C  GAUSSIAN PLUME MODEL FOR USE IN AN ALTERNATIVE METHOD OF STACK DESIGN
C                  PROGRAM NAME:  PLUMES
C
C  THE MAINLINE READS THE CONTROL DATA, STACK PARAMETERS AND METEOROLOGICAL
C  CONDITIONS.  EACH VALUE OR ITS MEANING IS DISPLAYED IN THE OUTPUT.
C  THE MAINLINE THEN ROUTES THE DATA TO THE APPROPRIATE SUBPROGRAMS FOR
C  COMPUTATION OF THE HORIZONTAL CONCENTRATION FIELD IN THE HEIGHT PLANE
C  SPECIFIED.  THE OUTPUT IS AUTOMATICALLY DIVIDED INTO A NUMBER OF PAGES
C  AND THE MAXIMUM VALUE FOR EACH PAGE, TOGETHER WITH THE LOCATION IS
C  IDENTIFIED.  THERE MAY BE MORE THAN ONE OCCURRENCE OF THE VALUE,
C  BUT THIS MUST BE ASCERTAINED BY INSPECTION OF THE GRID OF VALUES THAT
C  HAVE BEEN PRINTED.  ONLY ONE COMBINATION OF CONDITIONS CAN BE
C  SPECIFIED IN THE INPUT DATA SET, BUT ANY NUMBER OF DATA SETS MAY
C  BE RUN AT ONE TIME SIMPLY BY CHAINING THEM TOGETHER.  ALL CONSTANTS
C  ARE ASSIGNED VALUES WITHIN THE SUBPROGRAM TO WHICH THEY APPLY.
C  EACH MAJOR STEP IN THE CALCULATIONS OCCUPIES A SEPARATE SUBPROGRAM
C  SO THAT CHANGES TO THE FORMULATIONS CAN BE EASILY MADE FOR ANY
C  PARTICULAR APPLICATION.
C
0001        DIMENSION HS(50),D(50),DIS(50),STANG(50),VS(50),TG(50),Q(50),
           *ITITLE(20),XREL(50),YREL(50),CONC(14),H(50,14),TREF(50)
0002        COMMON ZA
0003      10 READ(5,100,END=400)ITITLE
0004      100 FORMAT(20A4)
0005        WRITE(6,104)ITITLE
0006      104 FORMAT('1',20A4/)
          C  READ AND WRITE REPORT TITLE
0007        READ(5,101) WSPD,WDIR,ZA,TA
0008      101 FORMAT(4F10.5)
0009        READ(5,90) IPSC,IRT,MT,DTDZ,DML,AVTH
0010       90   FORMAT(3I2,4X,5F10.3)
0011        READ(5,95) NSTACK,DD2,DD1,XINC,DC2,DC1,YINC,ZPLANE
0012       95 FORMAT(I2,8F7F10.0)
0013        AVTEAVTH+273.0
          C  READ IN PARAMETERS
0014        INCX = XINC
0015        INCY = YINC
0016        WRITE(6,106) WSPD,WDIR,ZA,TA
0017      106 FORMAT('0',5X,'WIND SPEED =',F8.0,2X,'M/S'/
           *' ',5X,'WIND DIRECTION =',F8.0,2X,'DEGREES FROM TRUE NORTH'/
           *' ',5X,'THERMOMETER HEIGHT =',F8.0,2X,'M'/
           *'0','AMBIENT TEMPERATURE =',F8.0,2X,'C')
0018        WRITE(6,250)
0019      250 FORMAT('0','FLAT TERRAIN')
0020        IF(IRT.EQ.1) WRITE(6,251)
0021      251 FORMAT('0','ROUGHNESS = 1 CM')
0022        IF(IRT.EQ.2) WRITE(6,252)
0023      252 FORMAT('0','ROUGHNESS = 10 CM')
0024        IF(IRT.EQ.3) WRITE(6,253)
0025      253 FORMAT('0','ROUGHNESS = 100 CM')
0026        IF(MT.EQ.0) WRITE(6,500)
0027      500 FORMAT('0','UNLIMITED MIXING')
0028        IF(MT.EQ.1.AND.IPSC.EQ.4) WRITE(6,510) DML
0029      510 FORMAT('0','ELEVATED INVERSION BASED AT',F8.0,2X,'M')
0030        IF(MT.EQ.1.AND.IPSC.EQ.5) WRITE(6,520)
0031      520 FORMAT('0','INVERSION BREAK-UP (MORNING FUMIGATION)')
0032        IF(MT.EQ.1.OR.IPSC.EQ.4) WRITE(6,515) DTDZ
0033      515 FORMAT(' ','TEMPERATURE GRADIENT THROUGH INVERSION =',F5.2,2X,'K/M
           *')
0034        IF(IPSC.EQ.1) WRITE(6,170)
0035        IF(IPSC.EQ.2) WRITE(6,180)
0036        IF(IPSC.EQ.3) WRITE(6,190)
0037        IF(IPSC.EQ.4) WRITE(6,200)
0038        IF(IPSC.EQ.5) WRITE(6,210)
0039        IF(IPSC.EQ.6) WRITE(6,220)
0040      170 FORMAT('0','PASQUILL STABILITY CATEGORY A /EXTREMELY UNSTABLE')
0041      180 FORMAT('0','PASQUILL STABILITY CATEGORY B/MODERATELY UNSTABLE')
0042      190 FORMAT('0','PASQUILL STABILITY CATEGORY C /SLIGHTLY UNSTABLE')
0043      200 FORMAT('0','PASQUILL STABILITY CATEGORY D /NEUTRAL')
0044      210 FORMAT('0','PASQUILL STABILITY CATEGORY E /SLIGHTLY STABLE')
0045      220 FORMAT('0','PASQUILL STABILITY CATEGORY F /MODERATELY STABLE')
0046        WRITE(6,107) DD2,DD1,XINC,DC2,DC1,YINC
```

```
0047            107 FORMAT('-','DOWNWIND DISTANCES'/' ',12X,'MAXIMUM =',F8.0,2X,'M'/
                   *' ',12X,'MINIMUM =',F8.0,2X,'M'/' ',10X,'INCREMENT =',F8.0,2X,'M'/
                   *'0','CROSSWIND DISTANCES'/' ',12X,'MAXIMUM =',F8.0,2X,'M'/
                   *' ',12X,'MINIMUM =',F8.0,2X,'M'/' ',10X,'INCREMENT =',F8.0,2X,'M')
0048              WRITE(6,103) NSTACK
0049            108  FORMAT('-',3X,'NUMBER OF STACKS =',I5)
0050                 DO 5 I=1,NSTACK
0051                 READ(5,102)HS(I),D(I),DIS(I),STANG(I),VS(I),TG(I),Q(I),TREF(I)
0052              102 FORMAT(8F10.4)
                  C  READ IN STACK DATA
0053                 ANGLE =(WDIR-180.-STANG(I))/57.2958
                  C  DETERMINE ANGLE RELATIVE TO WIND
0054                 XREL(I)= DIS(I)*COS(ANGLE)
0055                 YREL(I)= DIS(I)*SIN(ANGLE)
                  C  DETERMINE RELATIVE POSITIONS
0056                 WRITE(6,105)I,HS(I),D(I),DIS(I),STANG(I),VS(I),TG(I),Q(I),
                   *TREF(I),XREL(I),YREL(I)
                  C  WRITE DATA FOR EACH STACK
0057              105 FORMAT('-','PARAMETERS FOR STACK',1X,I2/
                   *' ',10X,'STACK HEIGHT =',F8.0,2X,'M'/
                   *' ',8X,'STACK DIAMETER =',F8.2,2X,'M'/
                   *' ',8X,'STACK DISTANCE =',F8.0,2X,'M  FROM ORIGIN'/
                   *' ',11X,'STACK ANGLE =',F8.0,2X,'DEGREES FROM TRUE NORTH'/
                   *' ',10X,'GAS VELOCITY =',F8.0,2X,'M/S'/
                   *' ',7X,'GAS TEMPERATURE =',F8.0,2X,'C'/
                   *' ',9X,'EMISSION RATE =',F8.6,2X,'M**3/S AT 101.325 KPA AND REFERE
                   *NCE TEMPERATURE'/
                   *' ',1X,'REFERENCE TEMPERATURE =',F8.1,2X,'C'/
                   *' ',12X,'X RELATIVE =',F8.0,2X,'M'/
                   *' ',12X,'Y RELATIVE =',F8.0,2X,'M')
0058                 Q(I)=Q(I)*(TA+273.16)/(TREF(I)+273.16)
0059                 UHS=WIND(IPSC,ZA,PSPD,HS(I),IRT)
                  C  CHECK FOR 'FLAGGING' OR 'CREEP'
0060                 IF(VS(I)/UHS.LT.1.5) WRITE(6,260)
0061              260  FORMAT('0',5X,'***** STACK AERODYNAMIC DOWNWASH OCCURS UNDER THE S
                   *PECIFIED ATMOSPHERIC CONDITIONS *****')
0062                5 CONTINUE
                  C  CALCULATIONS FOR GRID SIZE
0063                 NCOL = (DD2 - DD1)/ XINC + 1.5
0064                 NROW =(DC2-DC1)/ YINC + 1.5
0065                 NPART=MOD(NCOL,14)
0066                 IF(NPART.EQ.0) NPAGES=NCOL/14
0067                 IF(NPART.GT.0) NPAGES=NCOL/14 + 1
0068                 IDC2= DC2
0069                 IDD2= DD2
0070                 LB =DD1
0071                 DO 48 NN=1,NPAGES
0072                 IUL = LB +INCX * 13
0073                 IF(NN.EQ.NPAGES.AND.NPART.GT.0) IUL=LB + INCX*(NPART-1)
0074                 WRITE(6,110) AVTH,ZPLANE
0075              110 FORMAT('1',20X,'CUMULATIVE POLLUTANT CONCENTRATION IN PPM AS A',F5
                   *.2,2X,'HOUR AVERAGE AT A HEIGHT OF',F5.0,2X,'M ABOVE THE GROUND'/
                   *' ','CROSSWIND'/
                   *' ','DISTANCE',20X,'DOWNWIND DISTANCE IN METERS'/
                   *' ',1X,'(M)')
0076                 WRITE(6,111)(M,M=LB,IUL,INCX)
0077              111 FORMAT(' ',5X,14(4X,I5))
0078                 WRITE(6,523)
0079              523 FORMAT(' ')
0080                 VMAX=0.0
0081                 DO 40 JK=1,NROW
0082                 JJ = IDC2-(JK-1)*INCY
0083                 II=0
0084                 DO 32 K=1,14
0085              32 CONC(K)=0.0
0086                 DO 42 IJ=LB,IUL,INCX
0087                 II=II + 1
0088                 DO 35 J=1,NSTACK
0089                 XABS = IJ- XREL(J)
0090                 YABS = JJ- YREL(J)
0091                 IF(XABS.LE.0.0) H(J,II)=999999999999.
                  C  IF CALCULATION POINT IS NOT DOWNWIND OF STACK, ASTERISKS WILL BE
                  C  PRINTED FOR THE EFFECTIVE STACK HEIGHT
```

```
0092                  IF(XABS.LE.0.0) GO TO 35
0093                  UHS=WIND(IPSC,ZA,WSPD,HS(J),IRT)
0094                  R=D(J)/2.
0095                  H(J,II)=HS(J)+RISE(R,VS(J),TG(J),TA,HS(J),UHS,XABS,IPSC,DTDZ)
              C  CORRECT FOR STACK AERODYNAMIC DOWNWASH (BRIGGS, 1973)
0096                  IF(VS(J)/UHS.LT.1.5) H(J,II)=H(J,II)-2.*(1.5-VS(J)/UHS)*D(J)
0097                  IF(MT.EQ.0) CCN=CHI(Q(J),IPSC,XABS,H(J,II),WSPD,IRT,YABS,ZPLANE,AV
                     *T)
0098                  IF(MT.EQ.1.AND.IPSC.LE.4) CCN=TPAP(Q(J),WSPD,XABS,H(J,II),IPSC,R,
                     *VS(J),TG(J),TA,HS(J),DML,IRT,DTDZ,YABS,ZPLANE,AVT)
0099                  IF(MT.EQ.1.AND.IPSC.GE.5) CCN=FUMIG(Q(J),WSPD,XABS,H(J,II),IPSC,R,
                     *VS(J),TG(J),TA,HS(J),IRT,DTDZ,YABS,ZPLANE,AVT)
0100                  CONC(II)=CONC(II)+ CCN
0101                35 CONTINUE
0102                42 CONTINUE
0103                  NM=(IUL-LB)/INCX + 1
0104                  DO 44 IMAX=1,NM
0105                  IF(CONC(IMAX).LT.VMAX) GO TO 44
0106                  VMAX =CONC(IMAX)
              C  DETERMINE MAXIMUM CONCENTRATION
0107                  IYY = JJ
0108                  IXX = LB +INCX *(IMAX-1)
0109                44 CONTINUE
0110                  WRITE(6,112)JJ,(CONC(M),M=1,NM)
0111               112 FORMAT(' ',I5,14F9.3)
0112                40 CONTINUE
0113                  WRITE(6,113)VMAX,IXX,IYY
0114               113 FORMAT('-',20X,'MAXIMUM CONCENTRATION IN THE ABOVE TABLE IS '
                     *,F9.3,2X,'PPM AND OCCURS AT (',I6,1X,',',I6,1X,')'//)
0115                  WRITE(6,116)
0116               116 FORMAT('-','STACK',10X,'EFFECTIVE STACK HEIGHTS IN METRES AT ABOVE
                     * DOWNWIND DISTANCES'/)
0117                  DO 115 J=1,NSTACK
0118                  WRITE(6,117) J,(H(J,M),M=1,NM)
0119               117 FORMAT(' ',I5,14F9.0)
0120               115 CONTINUE
0121                  LB = IUL +INCX
0122                48 CONTINUE
0123                  GOTO 10
0124               400 STOP
0125                  END
```

```
      C
      C  THE FUNCTION 'WIND' GIVES THE WINDSPEED AT ANY HEIGHT USING THE WIND
      C  SPEED AT ANEMOMETER HEIGHT AND THE POWER LAWS OF IRWIN (1979)
      C
0001        FUNCTION WIND(IPSC,Z1,UZ1,Z2,IRT)
0002        DIMENSION PU(6,3)
0003        DATA PU/0.05,0.06,0.06,0.12,0.34,0.53,0.08,0.09,0.11,0.16,0.32,0.5
           *4,0.17,0.17,0.20,0.27,0.38,0.61/
0004        WIND=UZ1*(Z2/Z1)**PU(IPSC,IRT)
0005        RETURN
0006        END
```

```
                C
                C  THE FUNCTION 'RISE' GIVES THE PLUME RISE DUE TO BUOYANCY OR MOMENTUM
                C  ACCORDING TO FORMULAS OF BRIGGS (1969,1970) WITH THE CONSTANTS
                C  RECOMMENDED BY BRIGGS (1969,1975)
                C
0001                FUNCTION RISE(R,WS,TG,TA,HS,UHS,X,IPSC,DTDZ)
0002                DATA C1/1.6/,C2/2.6/,G/9.8/,DALR/0.01/,C3/2.3/,C4/1.5/
0003                TAK=TA+273.16
0004                TGK=TG+273.16
0005                F=R*R*WS*G*(TGK-TAK)/TGK
0006                FM=WS*WS*R*R*TAK/TGK
0007                IF(IPSC.GE.5) GOTO 10
0008                IF(F.LE.55.) XSTAR=14.*F**0.625
0009                IF(F.GT.55.) XSTAR=34.*F**0.4
0010                XFR=3.5*XSTAR
0011                IF(X.LT.XFR) HRB=C1*F**(1./3.)*X**(2./3.)/UHS
0012                IF(X.GE.XFR) HRB=C1*F**(1./3.)*XFR**(2./3.)/UHS
0013                HRMT=C3*FM**(1./3.)*X**(1./3.)/UHS**(2./3.)
0014                HRMF=6.*R*WS/UHS
0015                HRM=AMIN1(HRMT,HRMF)
0016                RISE=AMAX1(HRM,HRB)
0017                RETURN
0018             10 S=G*(DALR +DTDZ)/TAK
0019                HRB=C1*F**(1./3.)*X**(2./3.)/UHS
0020                HRS=C2*(F/UHS/S)**(1./3.)
0021                IF(HRS.LT.HRB) HRB=HRS
0022                HRMT=C3*FM**(1./3.)*X**(1./3.)/UHS**(2./3.)
0023                HRMS=C4*(FM/UHS)**(1./3.)/S**(1./6.)
0024                HRM=AMIN1(HRMT,HRMS)
0025                RISE=AMAX1(HRB,HRM)
0026                RETURN
0027                END
```

```
                C
                C  THE FUNCTION 'CHI' GIVES THE CONCENTRATION AT THE POINT (X,Y,Z) DUE
                C  TO A PLUME AT HEIGHT H IN HOMOGENEOUS ATMOSPHERES (UNLIMITED MIXING)
                C
0001                FUNCTION CHI(Q,IPSC,X,H,U,IRT,Y,Z,AVT)
0002                COMMON ZA
0003                SIGMAY=SIGY(IPSC,X,IRT,AVT)
0004                SIGMAZ=SIGZ(IPSC,X,IRT)
0005                S1=(Z-H)/SIGMAZ
0006                IF(ABS(S1).GT.10.) S1=10.
0007                S2=(Z+H)/SIGMAZ
0008                IF(ABS(S2).GT.10.) S2=10.
0009                ZEQ=0.62*SIGMAZ
0010                ZUB=MAX1(H,ZEQ)
0011                UBAR=WIND(IPSC,ZA,U,ZUB,IRT)
0012                F1=Q*1000000./(2.*3.14159*UBAR*SIGMAY*SIGMAZ)
0013                IF(ABS(Y/SIGMAY).LE.10.)  F2=EXP(-0.5*(Y/SIGMAY)*(Y/SIGMAY))
0014                IF(ABS(Y/SIGMAY).GT.10.) F2=0.0
0015                F3=EXP(-0.5*S1*S1) +EXP(-0.5*S2*S2)
0016                CHI=F1*F2*F3
0017                RETURN
0018                END
```

```
C
C  THE FUNCTION 'SIGY' GIVES THE LATERAL PLUME SPREAD ACCORDING TO
C  A SIMPLE POWER LAW.  THE VALUES USED HERE FIT THE PASQUILL-GIFFORD
C  CURVES FOR 10 CM ROUGHNESS AND ARE ADJUSTED APPROXIMATELY HALF A
C  STABILITY CATEGORY UPWARDS FOR 100 CM ROUGHNESS AND DOWNWARDS FOR
C  1 CM ROUGHNESS.
C
0001        FUNCTION SIGY(IPSC,X,IRT,AVT)
0002        DIMENSION SIGYR(6),RR(3)
0003        DATA PY/0.85/,SIGYR/200.,160.,100.,70.,52.,35./,XREF/1000./
0004        DATA RR/0.8,1.0,1.2/
0005        SIGY=SIGYR(IPSC)*(X/XREF)**PY*RR(IRT)
0006        SIGY=SIGY*(AVT/180.)**0.2
0007        RETURN
0008        END
```

```
C
C     THE FUNCTION 'SIGZ' GIVES THE VERTICAL PLUME SPREAD FOR EACH OF THREE
C     ROUGHNESSES AS GIVEN BY  F.B. SMITH (PASQUILL, 1974)
C
0001        FUNCTION SIGZ(IPSC,X,IRT)
0002        DIMENSION SIGZR(6,3),PZ(6,3)
0003        DATA XREF/1000./,SIGZR/102.,62.,43.,29.,17.,9.,140.,80.,56.,38.,23
           *.,12.,190.,110.,77.,50.,31.,17./,PZ/0.94,0.89,0.85,0.81,0.78,0.72,
           *0.90,0.85,0.80,0.76,0.73,0.67,0.83,0.77,0.72,0.68,0.65,0.58/
0004        SIGZ=SIGZR(IPSC,IRT)*(X/XREF)**PZ(IPSC,IRT)
0005        RETURN
0006        END
```

```
C
C  THE FUNCTION 'FUMIG' GIVES AN ESTIMATE OF THE MAXIMUM CONCENTRATION
C  THAT WOULD OCCUR DURING AN INVERSION BREAKUP.  AT SHORT RANGE THIS
C  IS CALCULATED AS A PLUME EMBEDDED IN AN ELEVATED INVERSION 'LEAKING'
C  INTO THE MIXING LAYER BELOW, WHILE AT LONGER RANGE THE SUDDEN
C  DOWNWARD MIXING IS EXPRESSED BY MEANS OF THE BIERLY AND HEWSON (1962)
C  EQUATION WITH THE LATERAL SPREAD RELATIONSHIP GIVEN BY TVA (1970).
C
0001          FUNCTION FUMIG(Q,U,X,H,IPSC,R,VS,TG,TA,HS,IRT,DTDZ,Y,Z,AVT)
0002          COMMON ZA
0003          DATA EDH/10./
C  ESTIMATE THE FIRST DISTANCE FOR FUMIGATION TO OCCUR
0004          TF1=(H*H-HS*HS)/(4.*EDH)
0005          USTAB=WIND(IPSC,ZA,U,H,IRT)
0006          XF1=USTAB*TF1
0007          HTOP=H+2.15*SIGZ(IPSC,XF1,IRT)
0008          TFUM=(HTOP*HTOP-HS*HS)/(4.*EDH)
0009          XFUM=USTAB*TFUM
0010          IF(X.LE.XFUM) GOTO 10
0011          HI=H+2.15*SIGZ(IPSC,X,IRT)
0012          SGMYF=SIGY(IPSC,X,IRT,AVT) + 0.47*H
0013          ZUB=0.62*HI
0014          UBAR=WIND(4,ZA,U,ZUB,IRT)
0015          F1=Q*1000000./(SQRT(2.*3.14159)*UBAR*SGMYF*HI)
0016          IF(ABS(Y/SGMYF).LE.10.)  F2=EXP(-0.5*(Y/SGMYF)*(Y/SGMYF))
0017          IF(ABS(Y/SGMYF).GT.10.) F2=0.
0018          FUMIG=F1*F2
0019          RETURN
0020    10    H=H+0.3*(H-HS)
C  THIS IS THE APPROXIMATE EQUILIBRIUM HEIGHT OF A PLUME RISING THROUGH
C  A DRY ADIABATIC MIXING LAYER INTO A THICK, ELEVATED STABLE LAYER, AS
C  GIVEN BY BRIGGS (1975)
0021          FUMIG=CHI(Q,S,X,H,U,IRT,Y,Z,AVT)
0022          RETURN
0023          END
```

```
                C
                C  THE FUNCTION 'TRAP' GIVES THE CONCENTRATION AT ANY POINT (X,Y,Z)
                C  WHEN THERE IS AN INVERSION LID ABOVE THE PLUME.  IF THE PLUME
                C  RISE IN NEUTRAL CONDITIONS WOULD PLACE THE PLUME ABOVE THE MIXING
                C  LAYER, THE PLUME RISE APPROPRIATE TO THE INVERSION ALONE IS CALCULATED.
                C  IF THIS IS LESS THAN THE HEIGHT OF THE MIXING LAYER, THEN THE PLUME
                C  IS ASSUMED TO BE TRAPPED AT THE BASE OF THE INVERSION LAYER.  OTHERWISE
                C  THE PLUME IS ASSUMED TO DIFFUSE ACCORDING TO A CLASS E STABILITY,
                C  THEREBY ALLOWING FOR SOME 'LEAKAGE' INTO THE MIXING LAYER.
                C
0001                    FUNCTION TRAP(Q,U,X,H,IPSC,R,VS,TG,TA,HS,DML,IRT,DTDZ,Y,Z,AVT)
0002                    COMMON ZA
0003                    SIGMAZ=SIGZ(IPSC,X,IRT)
0004                    SIGMAY=SIGY(IPSC,X,IRT,AVT)
0005                    IF(H.GT.DML) GOTO 20
0006                5   SUM=0.0
0007                    DO 10 N=1,10
0008                    S1=(Z-H-2.*FLOAT(N)*DML)/SIGMAZ
0009                    S2=(Z+H-2.*FLOAT(N)*DML)/SIGMAZ
0010                    S1N=(Z-H+2.*FLOAT(N)*DML)/SIGMAZ
0011                    S2N=(Z+H+2.*FLOAT(N)*DML)/SIGMAZ
0012                    IF(ABS(S1).GT.10.0) S1=10.0
0013                    IF(ABS(S2).GT.10.0) S2=10.0
0014                    IF(ABS(S1N).GT.10.0) S1N=10.0
0015                    IF(ABS(S2N).GT.10.0) S2N=10.0
0016                    SUM=SUM+EXP(-0.5*S1*S1)+EXP(-0.5*S2*S2)+EXP(-0.5*S1N*S1N)+EXP(-0.5
                       **S2N*S2N)
0017                10  CONTINUE
0018                    S3=(Z+H)/SIGMAZ
0019                    S3N=(Z-H)/SIGMAZ
0020                    IF(ABS(S3).GT.10.) S3=10.
0021                    IF(ABS(S3N).GT.10.) S3N=10.0
                C  CALCULATE THE HEIGHT FOR THE 'MEAN EQUIVALENT WIND'
0022                    ZEQ1=0.62*DML
0023                    ZEQ2=0.62*SIGMAZ
0024                    ZEQ=MIN1(ZEQ1,ZEQ2)
0025                    ZUB=MAX1(H,ZEQ)
0026                    UBAR=WIND(IPSC,ZA,U,ZUB,IRT)
0027                    F1=Q*1000000./(2.*3.14159*UBAR*SIGMAY*SIGMAZ)
0028                    F2=EXP(-0.5*S3*S3) + EXP(-0.5*S3N*S3N) + SUM
0029                    IF(ABS(Y/SIGMAY).LE.10.) F3=EXP(-0.5*(Y/SIGMAY)*(Y/SIGMAY))
0030                    IF(ABS(Y/SIGMAY).GT.10.) F3=0.
0031                    TRAP=F1*F2*F3
0032                    RETURN
0033                20  UHS=WIND(IPSC,ZA,U,HS,IRT)
                C  CALCULATE THE PLUME HEIGHT ASSUMING THE INVERSION LAYER ONLY
0034                    HMIN=HS + RISE(R,VS,TG,TA,HS,UHS,X,5,DTDZ)
0035                    IF(HMIN.LT.DML) H=DML
0036                    IF(HMIN.LT.DML) GOTO 5
0037                    TRAP=CHI(Q,5,X,HMIN,U,IRT,Y,Z,AVT)
0038                    H=HMIN
0039                    RETURN
0040                    END
```

SAMPLE RUN: THERMAL POWER PLANT - TWO STACKS, UNLIMITED MIXING

```
      WIND SPEED =      5.  M/S
  WIND DIRECTION =    270.  DEGREES FROM TRUE NORTH
ANEMOMETER HEIGHT =    10.  M

AMBIENT TEMPERATURE =    21.  C

FLAT TERRAIN
ROUGHNESS = 10 CM

UNLIMITED MIXING

PASQUILL STABILITY CATEGORY C /SLIGHTLY UNSTABLE

DOWNWIND DISTANCES
          MAXIMUM =  14000.  M
          MINIMUM =    500.  M
        INCREMENT =    500.  M

CROSSWIND DISTANCES
          MAXIMUM =   2000.  M
          MINIMUM =  -2000.  M
        INCREMENT =    100.  M

   NUMBER OF STACKS =    2

PARAMETERS FOR STACK  1

        STACK HEIGHT =    100.  M
      STACK DIAMETER =   5.00  M
      STACK DISTANCE =      0.  M  FROM ORIGIN
         STACK ANGLE =      0.  DEGREES FROM TRUE NORTH
      GAS VELOCITY =     20.  M/S
    GAS TEMPERATURE =    150.  C
     EMISSION RATE =0.350000  M**3/S AT 101.325 KPA AND REFERENCE TEMPERATURE
REFERENCE TEMPERATURE =   25.0  C
          X RELATIVE =      0.  M
          Y RELATIVE =      0.  M

PARAMETERS FOR STACK  2

        STACK HEIGHT =     75.  M
      STACK DIAMETER =   3.00  M
      STACK DISTANCE =     50.  M  FROM ORIGIN
         STACK ANGLE =    100.  DEGREES FROM TRUE NORTH
      GAS VELOCITY =     20.  M/S
    GAS TEMPERATURE =    150.  C
     EMISSION RATE =0.200000  M**3/S AT 101.325 KPA AND REFERENCE TEMPERATURE
REFERENCE TEMPERATURE =   25.0  C
          X RELATIVE =     49.  M
          Y RELATIVE =     -9.  M
```

CUMULATIVE POLLUTANT CONCENTRATION IN PPM AS A 0.50 HOUR AVERAGE AT A HEIGHT OF 0. M ABOVE THE GROUND

CROSSWIND DISTANCE (M)	DOWNWIND DISTANCE IN METERS													
	500	1000	1500	2000	2500	3000	3500	4000	4500	5000	5500	6000	6500	7000
2000	0.0	0.0	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.001	0.002	0.003	0.005
1900	0.0	0.0	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.002	0.003	0.005	0.006
1800	0.0	0.0	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.002	0.003	0.004	0.006	0.008
1700	0.0	0.0	0.000	0.000	0.000	0.000	0.000	0.001	0.001	0.003	0.004	0.006	0.008	0.009
1600	0.0	0.0	0.000	0.000	0.000	0.000	0.000	0.001	0.002	0.004	0.006	0.008	0.010	0.012
1500	0.0	0.000	0.000	0.000	0.000	0.000	0.001	0.002	0.003	0.005	0.008	0.010	0.012	0.014
1400	0.0	0.000	0.000	0.000	0.000	0.000	0.001	0.003	0.005	0.008	0.011	0.013	0.015	0.017
1300	0.0	0.000	0.000	0.000	0.000	0.001	0.002	0.004	0.007	0.011	0.014	0.017	0.019	0.021
1200	0.0	0.000	0.000	0.000	0.000	0.001	0.003	0.007	0.010	0.014	0.018	0.021	0.023	0.024
1100	0.0	0.000	0.000	0.000	0.000	0.002	0.005	0.010	0.014	0.019	0.022	0.025	0.027	0.028
1000	0.0	0.000	0.000	0.000	0.001	0.004	0.009	0.014	0.020	0.024	0.028	0.030	0.032	0.033
900	0.0	0.000	0.000	0.000	0.002	0.007	0.013	0.020	0.026	0.030	0.033	0.035	0.037	0.037
800	0.000	0.000	0.000	0.001	0.005	0.011	0.019	0.027	0.033	0.037	0.040	0.041	0.041	0.041
700	0.000	0.000	0.000	0.002	0.009	0.018	0.027	0.035	0.041	0.044	0.046	0.047	0.046	0.046
600	0.000	0.000	0.000	0.005	0.015	0.026	0.037	0.044	0.049	0.052	0.052	0.052	0.051	0.050
500	0.000	0.000	0.001	0.010	0.023	0.036	0.047	0.054	0.057	0.059	0.059	0.057	0.056	0.053
400	0.000	0.000	0.004	0.017	0.034	0.048	0.057	0.063	0.065	0.065	0.064	0.062	0.059	0.057
300	0.000	0.000	0.008	0.026	0.045	0.059	0.067	0.071	0.072	0.071	0.069	0.066	0.063	0.059
200	0.000	0.001	0.014	0.036	0.056	0.068	0.075	0.078	0.078	0.076	0.073	0.069	0.065	0.061
100	0.000	0.001	0.019	0.044	0.063	0.075	0.081	0.082	0.081	0.078	0.075	0.071	0.067	0.062
0	0.000	0.002	0.021	0.047	0.066	0.077	0.083	0.084	0.083	0.079	0.076	0.071	0.067	0.063
-100	0.000	0.002	0.020	0.045	0.064	0.076	0.081	0.083	0.081	0.079	0.075	0.071	0.067	0.063
-200	0.000	0.001	0.015	0.038	0.057	0.069	0.076	0.079	0.078	0.076	0.073	0.069	0.065	0.061
-300	0.000	0.000	0.009	0.028	0.047	0.060	0.068	0.072	0.073	0.072	0.069	0.066	0.063	0.059
-400	0.000	0.000	0.004	0.018	0.035	0.049	0.059	0.064	0.066	0.066	0.065	0.062	0.060	0.057
-500	0.000	0.000	0.002	0.011	0.025	0.038	0.048	0.055	0.058	0.059	0.059	0.058	0.056	0.054
-600	0.000	0.000	0.001	0.006	0.016	0.027	0.038	0.045	0.050	0.052	0.053	0.053	0.052	0.050
-700	0.000	0.000	0.000	0.003	0.009	0.019	0.028	0.036	0.041	0.045	0.047	0.047	0.047	0.046
-800	0.000	0.000	0.000	0.001	0.005	0.012	0.020	0.028	0.034	0.038	0.040	0.042	0.042	0.042
-900	0.0	0.000	0.000	0.000	0.003	0.007	0.014	0.021	0.026	0.031	0.034	0.036	0.037	0.037
-1000	0.0	0.000	0.000	0.000	0.001	0.004	0.009	0.015	0.020	0.025	0.028	0.031	0.032	0.033
-1100	0.0	0.000	0.000	0.000	0.001	0.002	0.006	0.010	0.015	0.019	0.023	0.026	0.027	0.029
-1200	0.0	0.000	0.000	0.000	0.000	0.001	0.003	0.007	0.011	0.015	0.018	0.021	0.023	0.025
-1300	0.0	0.000	0.000	0.000	0.000	0.001	0.002	0.004	0.008	0.011	0.014	0.017	0.019	0.021
-1400	0.0	0.000	0.000	0.000	0.000	0.000	0.001	0.003	0.005	0.008	0.011	0.013	0.016	0.018
-1500	0.0	0.000	0.000	0.000	0.000	0.000	0.001	0.002	0.003	0.006	0.008	0.011	0.013	0.015
-1600	0.0	0.0	0.000	0.000	0.000	0.000	0.000	0.001	0.002	0.004	0.006	0.008	0.010	0.012
-1700	0.0	0.0	0.000	0.000	0.000	0.000	0.000	0.001	0.001	0.003	0.004	0.006	0.008	0.010
-1800	0.0	0.0	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.002	0.003	0.005	0.006	0.008
-1900	0.0	0.0	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.002	0.003	0.005	0.006
-2000	0.0	0.0	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.001	0.002	0.003	0.005

MAXIMUM CONCENTRATION IN THE ABOVE TABLE IS 0.084 PPM AND OCCURS AT (4000 , 0)

STACK	EFFECTIVE STACK HEIGHTS IN METRES AT ABOVE DOWNWIND DISTANCES													
1	213.	279.	310.	310.	310.	310.	310.	310.	310.	310.	310.	310.	310.	310.
2	152.	192.	192.	192.	192.	192.	192.	192.	192.	192.	192.	192.	192.	192.

CUMULATIVE POLLUTANT CONCENTRATION IN PPM AS A 0.50 HOUR AVERAGE AT A HEIGHT OF 0. M ABOVE THE GROUND

CROSSWIND DISTANCE (M)	DOWNWIND DISTANCE IN METERS													
	7500	8000	8500	9000	9500	10000	10500	11000	11500	12000	12500	13000	13500	14000
2000	0.006	0.007	0.008	0.009	0.010	0.011	0.011	0.012	0.012	0.012	0.012	0.012	0.012	0.012
1900	0.007	0.009	0.010	0.011	0.011	0.012	0.013	0.013	0.013	0.013	0.013	0.014	0.013	0.013
1800	0.009	0.010	0.011	0.012	0.013	0.014	0.014	0.014	0.015	0.015	0.015	0.015	0.015	0.014
1700	0.011	0.012	0.013	0.014	0.015	0.015	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.015
1600	0.013	0.015	0.016	0.016	0.017	0.017	0.018	0.018	0.018	0.017	0.017	0.017	0.017	0.016
1500	0.016	0.017	0.018	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.017	0.017	0.016
1400	0.019	0.020	0.021	0.021	0.021	0.021	0.021	0.021	0.021	0.020	0.020	0.019	0.018	0.017
1300	0.022	0.023	0.024	0.024	0.024	0.024	0.023	0.023	0.022	0.022	0.021	0.019	0.019	0.018
1200	0.026	0.026	0.026	0.026	0.026	0.026	0.025	0.025	0.024	0.023	0.022	0.021	0.020	0.019
1100	0.029	0.029	0.029	0.029	0.028	0.028	0.027	0.026	0.025	0.025	0.024	0.022	0.021	0.020
1000	0.033	0.033	0.032	0.032	0.031	0.030	0.029	0.028	0.027	0.026	0.025	0.024	0.023	0.022
900	0.037	0.036	0.035	0.034	0.033	0.032	0.031	0.030	0.028	0.027	0.026	0.025	0.024	0.023
800	0.041	0.040	0.038	0.037	0.035	0.034	0.032	0.031	0.030	0.028	0.027	0.026	0.025	0.024
700	0.044	0.043	0.041	0.039	0.037	0.036	0.034	0.032	0.031	0.029	0.028	0.027	0.026	0.024
600	0.048	0.046	0.044	0.041	0.039	0.037	0.036	0.034	0.032	0.030	0.029	0.028	0.026	0.025
500	0.051	0.048	0.046	0.043	0.041	0.039	0.037	0.035	0.033	0.031	0.030	0.028	0.027	0.026
400	0.054	0.051	0.048	0.045	0.043	0.040	0.038	0.036	0.034	0.032	0.030	0.029	0.027	0.026
300	0.056	0.053	0.049	0.046	0.044	0.041	0.039	0.037	0.034	0.033	0.031	0.029	0.028	0.026
200	0.057	0.054	0.051	0.047	0.045	0.042	0.039	0.037	0.035	0.033	0.031	0.030	0.028	0.027
100	0.059	0.055	0.051	0.048	0.045	0.042	0.040	0.037	0.035	0.033	0.031	0.030	0.028	0.027
0	0.059	0.055	0.052	0.048	0.045	0.042	0.040	0.038	0.035	0.033	0.032	0.030	0.028	0.027
-100	0.059	0.055	0.051	0.048	0.045	0.042	0.040	0.037	0.035	0.033	0.031	0.030	0.028	0.027
-200	0.058	0.054	0.051	0.048	0.045	0.042	0.039	0.037	0.035	0.033	0.031	0.030	0.028	0.027
-300	0.056	0.053	0.050	0.047	0.044	0.041	0.039	0.037	0.035	0.033	0.031	0.029	0.028	0.026
-400	0.054	0.051	0.048	0.045	0.043	0.040	0.038	0.036	0.034	0.032	0.030	0.029	0.027	0.026
-500	0.051	0.049	0.046	0.044	0.041	0.039	0.037	0.035	0.033	0.031	0.030	0.028	0.027	0.026
-600	0.048	0.046	0.044	0.042	0.040	0.038	0.036	0.034	0.032	0.030	0.029	0.028	0.026	0.025
-700	0.045	0.043	0.041	0.039	0.038	0.036	0.034	0.033	0.031	0.030	0.028	0.027	0.026	0.024
-800	0.041	0.040	0.039	0.037	0.036	0.034	0.033	0.031	0.030	0.028	0.027	0.026	0.025	0.024
-900	0.037	0.036	0.035	0.035	0.033	0.032	0.031	0.030	0.028	0.027	0.026	0.025	0.024	0.023
-1000	0.033	0.033	0.033	0.032	0.031	0.030	0.029	0.028	0.027	0.026	0.025	0.024	0.023	0.022
-1100	0.029	0.030	0.030	0.029	0.029	0.028	0.027	0.026	0.025	0.025	0.024	0.023	0.022	0.021
-1200	0.026	0.026	0.027	0.027	0.026	0.026	0.025	0.025	0.024	0.023	0.023	0.022	0.021	0.020
-1300	0.023	0.023	0.024	0.024	0.024	0.024	0.023	0.023	0.022	0.022	0.021	0.021	0.020	0.019
-1400	0.019	0.020	0.021	0.021	0.022	0.022	0.021	0.021	0.021	0.020	0.020	0.019	0.019	0.018
-1500	0.016	0.017	0.018	0.019	0.019	0.020	0.020	0.019	0.019	0.019	0.019	0.018	0.018	0.017
-1600	0.014	0.015	0.016	0.017	0.017	0.018	0.018	0.018	0.018	0.018	0.017	0.017	0.017	0.016
-1700	0.011	0.013	0.014	0.015	0.015	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.015
-1800	0.009	0.010	0.012	0.013	0.013	0.014	0.014	0.015	0.015	0.015	0.015	0.015	0.015	0.014
-1900	0.007	0.009	0.010	0.011	0.012	0.012	0.013	0.013	0.013	0.013	0.014	0.014	0.014	0.013
-2000	0.006	0.007	0.008	0.009	0.010	0.011	0.011	0.012	0.012	0.012	0.012	0.012	0.013	0.012

MAXIMUM CONCENTRATION IN THE ABOVE TABLE IS 0.059 PPM AND OCCURS AT (7500 , 0)

STACK	EFFECTIVE STACK HEIGHTS IN METRES AT ABOVE DOWNWIND DISTANCES													
1	310.	310.	310.	310.	310.	310.	310.	310.	310.	310.	310.	310.	310.	310.
2	192.	192.	192.	192.	192.	192.	192.	192.	192.	192.	192.	192.	192.	192.

SAMPLE RUN: THERMAL POWER PLANT - ONE STACK, LIMITED MIXING

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      WIND SPEED =      3.  M/S
  WIND DIRECTION =    270.  DEGREES FROM TRUE NORTH
ANEMOMETER HEIGHT =    10.  M

AMBIENT TEMPERATURE =    21.  C

FLAT TERRAIN
ROUGHNESS = 10 CM

ELEVATED INVERSION BASED AT    150.  M
TEMPERATURE GRADIENT THROUGH INVERSION = 0.050  K/M

PASQUILL STABILITY CATEGORY D /NEUTRAL

DOWNWIND DISTANCES
          MAXIMUM =  14000.  M
          MINIMUM =    500.  M
        INCREMENT =    500.  M

CROSSWIND DISTANCES
          MAXIMUM =   2000.  M
          MINIMUM =  -2000.  M
        INCREMENT =    100.  M

   NUMBER OF STACKS =    1

PARAMETERS FOR STACK  1

        STACK HEIGHT =     75.  M
      STACK DIAMETER =   3.00  M
      STACK DISTANCE =     50.  M  FROM ORIGIN
         STACK ANGLE =    100.  DEGREES FROM TRUE NORTH
      GAS VELOCITY =      20.  M/S
    GAS TEMPERATURE =     150.  C
     EMISSION RATE =0.200000  M**3/S AT 101.325 KPA AND REFERENCE TEMPERATURE
REFERENCE TEMPERATURE =  25.0  C
          X RELATIVE =     49.  M
          Y RELATIVE =     -9.  M
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CUMULATIVE POLLUTANT CONCENTRATION IN PPM AS A 0.50 HOUR AVERAGE AT A HEIGHT OF 0. M ABOVE THE GROUND

CROSSWIND DISTANCE (M)	DOWNWIND DISTANCE IN METERS													
	500	1000	1500	2000	2500	3000	3500	4000	4500	5000	5500	6000	6500	7000
2000	0.0	0.0	0.0	0.0	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001
1900	0.0	0.0	0.0	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.001
1800	0.0	0.0	0.0	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.001	0.002
1700	0.0	0.0	0.0	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.001	0.002	0.004
1600	0.0	0.0	0.0	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.002	0.004	0.006
1500	0.0	0.0	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.002	0.004	0.006	0.009
1400	0.0	0.0	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.002	0.004	0.006	0.009	0.013
1300	0.0	0.0	0.000	0.000	0.000	0.000	0.000	0.001	0.002	0.004	0.007	0.010	0.014	0.019
1200	0.0	0.0	0.000	0.000	0.000	0.000	0.000	0.001	0.003	0.007	0.011	0.016	0.021	0.026
1100	0.0	0.0	0.000	0.000	0.000	0.000	0.001	0.003	0.007	0.012	0.018	0.024	0.030	0.036
1000	0.0	0.000	0.000	0.000	0.000	0.001	0.002	0.006	0.013	0.020	0.028	0.035	0.042	0.047
900	0.0	0.000	0.000	0.000	0.000	0.002	0.006	0.013	0.022	0.032	0.041	0.049	0.056	0.061
800	0.0	0.000	0.000	0.000	0.001	0.005	0.013	0.024	0.037	0.048	0.058	0.066	0.072	0.077
700	0.0	0.000	0.000	0.000	0.003	0.012	0.026	0.042	0.057	0.070	0.079	0.086	0.091	0.094
600	0.0	0.000	0.000	0.001	0.009	0.026	0.047	0.067	0.084	0.096	0.104	0.109	0.112	0.112
500	0.000	0.000	0.000	0.005	0.023	0.051	0.079	0.101	0.117	0.126	0.131	0.133	0.132	0.131
400	0.000	0.000	0.001	0.016	0.050	0.088	0.120	0.141	0.153	0.158	0.158	0.156	0.152	0.148
300	0.000	0.000	0.006	0.039	0.091	0.136	0.167	0.183	0.188	0.188	0.183	0.177	0.170	0.163
200	0.000	0.000	0.017	0.074	0.140	0.186	0.211	0.220	0.219	0.213	0.204	0.194	0.184	0.174
100	0.000	0.001	0.033	0.110	0.182	0.226	0.244	0.247	0.241	0.230	0.217	0.205	0.193	0.182
0	0.000	0.002	0.042	0.128	0.201	0.243	0.258	0.258	0.249	0.237	0.223	0.209	0.196	0.185
-100	0.000	0.001	0.035	0.115	0.188	0.231	0.248	0.250	0.243	0.232	0.219	0.206	0.194	0.183
-200	0.000	0.000	0.019	0.081	0.148	0.194	0.218	0.226	0.224	0.216	0.207	0.196	0.186	0.176
-300	0.000	0.000	0.007	0.044	0.099	0.145	0.175	0.190	0.194	0.192	0.187	0.180	0.173	0.165
-400	0.000	0.000	0.002	0.019	0.055	0.096	0.128	0.148	0.159	0.163	0.163	0.160	0.155	0.150
-500	0.000	0.000	0.000	0.006	0.027	0.055	0.085	0.108	0.123	0.131	0.136	0.137	0.136	0.134
-600	0.0	0.000	0.000	0.002	0.011	0.029	0.052	0.073	0.089	0.101	0.109	0.113	0.115	0.116
-700	0.0	0.000	0.000	0.000	0.004	0.013	0.029	0.045	0.061	0.074	0.083	0.090	0.095	0.097
-800	0.0	0.000	0.000	0.000	0.001	0.005	0.015	0.027	0.040	0.052	0.062	0.069	0.075	0.080
-900	0.0	0.000	0.000	0.000	0.000	0.002	0.007	0.015	0.024	0.034	0.044	0.052	0.058	0.064
-1000	0.0	0.000	0.000	0.000	0.000	0.001	0.003	0.007	0.014	0.022	0.030	0.037	0.044	0.050
-1100	0.0	0.0	0.000	0.000	0.000	0.000	0.001	0.003	0.008	0.013	0.019	0.026	0.032	0.037
-1200	0.0	0.0	0.000	0.000	0.000	0.000	0.000	0.002	0.004	0.007	0.012	0.017	0.022	0.028
-1300	0.0	0.0	0.000	0.000	0.000	0.000	0.000	0.001	0.002	0.004	0.007	0.011	0.015	0.020
-1400	0.0	0.0	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.002	0.004	0.007	0.010	0.014
-1500	0.0	0.0	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.002	0.004	0.007	0.009
-1600	0.0	0.0	0.0	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.002	0.004	0.006
-1700	0.0	0.0	0.0	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.001	0.002	0.004
-1800	0.0	0.0	0.0	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.001	0.003
-1900	0.0	0.0	0.0	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.002
-2000	0.0	0.0	0.0	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001

MAXIMUM CONCENTRATION IN THE ABOVE TABLE IS 0.258 PPM AND OCCURS AT (3500 , 0)

STACK	EFFECTIVE STACK HEIGHTS IN METRES AT ABOVE DOWNWIND DISTANCES													
1	150.	150.	150.	150.	150.	150.	150.	150.	150.	150.	150.	150.	150.	150.

CUMULATIVE POLLUTANT CONCENTRATION IN PPM AS A 0.50 HOUR AVERAGE AT A HEIGHT OF 0. M ABOVE THE GROUND

CROSSWIND DISTANCE (M)	DOWNWIND DISTANCE IN METERS												
	7500	8000	8500	9000	9500	10000	10500	11000	11500	12000	12500	13000	13500	14000
2000	0.001	0.002	0.003	0.005	0.006	0.008	0.009	0.011	0.013	0.014	0.016	0.018	0.019	0.021
1900	0.002	0.004	0.005	0.007	0.008	0.010	0.012	0.014	0.016	0.018	0.019	0.021	0.023	0.024
1800	0.004	0.005	0.007	0.009	0.011	0.013	0.015	0.017	0.019	0.021	0.023	0.025	0.026	0.028
1700	0.005	0.008	0.010	0.012	0.015	0.017	0.019	0.021	0.024	0.026	0.027	0.029	0.031	0.032
1600	0.008	0.011	0.013	0.016	0.019	0.021	0.024	0.026	0.028	0.030	0.032	0.034	0.035	0.036
1500	0.012	0.015	0.018	0.021	0.024	0.027	0.029	0.032	0.034	0.036	0.037	0.039	0.040	0.041
1400	0.017	0.020	0.024	0.027	0.030	0.033	0.035	0.038	0.040	0.041	0.043	0.044	0.045	0.046
1300	0.023	0.027	0.031	0.034	0.037	0.040	0.042	0.044	0.046	0.048	0.049	0.050	0.051	0.051
1200	0.031	0.035	0.039	0.042	0.045	0.048	0.050	0.052	0.053	0.054	0.055	0.056	0.056	0.057
1100	0.041	0.045	0.049	0.052	0.054	0.056	0.058	0.059	0.060	0.061	0.062	0.062	0.062	0.062
1000	0.052	0.056	0.059	0.062	0.064	0.066	0.067	0.067	0.068	0.068	0.068	0.068	0.068	0.067
900	0.065	0.069	0.071	0.073	0.074	0.075	0.076	0.076	0.076	0.075	0.075	0.074	0.073	0.073
800	0.080	0.083	0.084	0.085	0.085	0.085	0.085	0.084	0.083	0.082	0.081	0.080	0.079	0.078
700	0.096	0.097	0.097	0.097	0.096	0.095	0.093	0.092	0.090	0.089	0.087	0.086	0.084	0.083
600	0.112	0.111	0.110	0.108	0.106	0.104	0.102	0.100	0.097	0.095	0.093	0.091	0.089	0.087
500	0.128	0.125	0.122	0.119	0.116	0.113	0.109	0.106	0.104	0.101	0.098	0.096	0.093	0.091
400	0.143	0.139	0.133	0.129	0.124	0.120	0.116	0.113	0.109	0.106	0.103	0.100	0.097	0.094
300	0.156	0.149	0.143	0.137	0.131	0.126	0.122	0.117	0.113	0.110	0.106	0.103	0.100	0.097
200	0.165	0.157	0.150	0.143	0.137	0.131	0.126	0.121	0.117	0.113	0.109	0.105	0.102	0.099
100	0.172	0.163	0.154	0.147	0.140	0.134	0.129	0.124	0.119	0.115	0.110	0.107	0.103	0.100
0	0.174	0.165	0.156	0.149	0.142	0.135	0.130	0.124	0.119	0.115	0.111	0.107	0.104	0.101
-100	0.172	0.163	0.155	0.147	0.141	0.135	0.129	0.124	0.119	0.115	0.111	0.107	0.103	0.100
-200	0.167	0.158	0.151	0.144	0.138	0.133	0.127	0.122	0.117	0.113	0.109	0.106	0.102	0.099
-300	0.158	0.151	0.144	0.138	0.133	0.127	0.123	0.118	0.114	0.110	0.107	0.103	0.100	0.097
-400	0.145	0.140	0.135	0.130	0.126	0.121	0.117	0.113	0.110	0.106	0.103	0.100	0.097	0.095
-500	0.131	0.128	0.124	0.121	0.117	0.114	0.111	0.108	0.105	0.102	0.099	0.096	0.094	0.091
-600	0.115	0.114	0.112	0.110	0.108	0.106	0.103	0.101	0.098	0.096	0.094	0.092	0.090	0.088
-700	0.099	0.099	0.099	0.099	0.098	0.096	0.095	0.093	0.092	0.090	0.088	0.087	0.085	0.083
-800	0.083	0.085	0.086	0.087	0.087	0.087	0.086	0.085	0.084	0.083	0.082	0.081	0.080	0.079
-900	0.068	0.071	0.073	0.075	0.076	0.077	0.077	0.077	0.077	0.076	0.076	0.075	0.074	0.074
-1000	0.054	0.058	0.061	0.064	0.066	0.067	0.068	0.069	0.069	0.069	0.069	0.069	0.069	0.068
-1100	0.042	0.047	0.050	0.053	0.056	0.058	0.060	0.061	0.062	0.062	0.063	0.063	0.063	0.063
-1200	0.032	0.037	0.041	0.044	0.047	0.049	0.051	0.053	0.054	0.055	0.055	0.057	0.057	0.057
-1300	0.024	0.028	0.032	0.036	0.039	0.041	0.044	0.046	0.047	0.049	0.050	0.051	0.052	0.052
-1400	0.018	0.021	0.025	0.028	0.031	0.034	0.037	0.039	0.041	0.042	0.044	0.045	0.046	0.047
-1500	0.012	0.016	0.019	0.022	0.025	0.028	0.030	0.033	0.035	0.037	0.038	0.040	0.041	0.042
-1600	0.009	0.011	0.014	0.017	0.020	0.022	0.025	0.027	0.029	0.031	0.033	0.035	0.036	0.037
-1700	0.006	0.008	0.010	0.013	0.015	0.018	0.020	0.022	0.024	0.026	0.028	0.030	0.031	0.033
-1800	0.004	0.006	0.007	0.009	0.012	0.014	0.016	0.018	0.020	0.022	0.024	0.026	0.027	0.028
-1900	0.003	0.004	0.005	0.007	0.009	0.011	0.013	0.014	0.016	0.018	0.020	0.022	0.023	0.025
-2000	0.002	0.002	0.004	0.005	0.006	0.008	0.010	0.011	0.013	0.015	0.017	0.018	0.020	0.021

MAXIMUM CONCENTRATION IN THE ABOVE TABLE IS 0.174 PPM AND OCCURS AT (7500 , 0)

STACK	EFFECTIVE STACK HEIGHTS IN METRES AT ABOVE DOWNWIND DISTANCES												
1	150.	150.	150.	150.	150.	150.	150.	150.	150.	150.	150.	150.	150.

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SAMPLE RUN: THERMAL POWER PLANT - ONE STACK, INVERSION BREAKUP FUMIGATION

          WIND SPEED =      2.  M/S
      WIND DIRECTION =    270.  DEGREES FROM TRUE NORTH
  ANEMOMETER HEIGHT =     10.  M

AMBIENT TEMPERATURE =     21.  C

FLAT TERRAIN
ROUGHNESS = 10 CM

INVERSION BREAKUP (HEWSON FUMIGATION)
TEMPERATURE GRADIENT THROUGH INVERSION = 0.100  K/M

PASQUILL STABILITY CATEGORY F /MODERATELY STABLE

DOWNWIND DISTANCES
            MAXIMUM =  14000.  M
            MINIMUM =    500.  M
          INCREMENT =    500.  M

CROSSWIND DISTANCES
            MAXIMUM =   2000.  M
            MINIMUM =  -2000.  M
          INCREMENT =    100.  M

   NUMBER OF STACKS =    1

PARAMETERS FOR STACK  1

         STACK HEIGHT =      75.  M
       STACK DIAMETER =    3.00  M
       STACK DISTANCE =      50.  M  FROM ORIGIN
          STACK ANGLE =     100.  DEGREES FROM TRUE NORTH
         GAS VELOCITY =      20.  M/S
      GAS TEMPERATURE =     150.  C
       EMISSION RATE =0.200000  M**3/S AT 101.325 KPA AND REFERENCE TEMPERATURE
REFERENCE TEMPERATURE =    25.0  C
           X RELATIVE =     49.  M
           Y RELATIVE =     -9.  M
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CUMULATIVE POLLUTANT CONCENTRATION IN PPM AS A 0.50 HOUR AVERAGE AT A HEIGHT OF 0. M ABOVE THE GROUND

CROSSWIND DISTANCE (M)	DOWNWIND DISTANCE IN METERS												
	500	1000	1500	2000	2500	3000	3500	4000	4500	5000	5500	6000	6500	7000
2000	0.0	0.0	0.0	0.0	0.0	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1900	0.0	0.0	0.0	0.0	0.0	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1800	0.0	0.0	0.0	0.0	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1700	0.0	0.0	0.0	0.0	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1600	0.0	0.0	0.0	0.0	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1500	0.0	0.0	0.0	0.0	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1400	0.0	0.0	0.0	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1300	0.0	0.0	0.0	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.001
1200	0.0	0.0	0.0	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1100	0.0	0.0	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.001	0.002	0.003
1000	0.0	0.0	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.002	0.005	0.007
900	0.0	0.0	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.002	0.003	0.007	0.014
800	0.0	0.0	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.003	0.005	0.011	0.028
700	0.0	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.002	0.005	0.008	0.022	0.049
600	0.0	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.003	0.008	0.017	0.043	0.081
500	0.0	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.002	0.005	0.012	0.028	0.074	0.123
400	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.003	0.005	0.008	0.021	0.039	0.119	0.162
300	0.000	0.000	0.000	0.000	0.000	0.000	0.002	0.006	0.014	0.021	0.047	0.067	0.167	0.175
200	0.000	0.000	0.000	0.000	0.000	0.001	0.006	0.013	0.036	0.047	0.094	0.113	0.176	0.175
100	0.000	0.000	0.000	0.000	0.000	0.002	0.013	0.024	0.081	0.094	0.167	0.175	0.238	0.229
0	0.000	0.000	0.000	0.000	0.000	0.005	0.024	0.039	0.157	0.167	0.172	0.254	0.296	0.279
-100	0.000	0.000	0.000	0.000	0.000	0.011	0.037	0.054	0.262	0.260	0.254	0.315	0.339	0.315
-200	0.000	0.000	0.000	0.000	0.000	0.020	0.048	0.067	0.360	0.357	0.336	0.357	0.356	0.329
-300	0.000	0.000	0.000	0.000	0.000	0.029	0.053	0.072	0.477	0.435	0.398	0.388	0.373	0.319
-400	0.000	0.000	0.000	0.000	0.000	0.032	0.050	0.068	0.519	0.468	0.424	0.406	0.344	0.286
-500	0.000	0.000	0.000	0.000	0.000	0.030	0.039	0.057	0.489	0.444	0.406	0.348	0.305	0.238
-600	0.000	0.000	0.000	0.000	0.000	0.022	0.026	0.041	0.400	0.373	0.348	0.269	0.249	0.184
-700	0.000	0.000	0.000	0.000	0.000	0.013	0.015	0.026	0.283	0.277	0.269	0.186	0.186	0.132
-800	0.000	0.000	0.000	0.000	0.000	0.006	0.007	0.015	0.173	0.181	0.186	0.115	0.128	0.087
-900	0.000	0.000	0.000	0.000	0.000	0.002	0.003	0.007	0.092	0.105	0.115	0.073	0.081	0.054
-1000	0.0	0.000	0.000	0.000	0.000	0.001	0.001	0.003	0.042	0.054	0.064	0.040	0.047	0.031
-1100	0.0	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.017	0.024	0.032	0.020	0.025	0.016
-1200	0.0	0.0	0.000	0.000	0.000	0.000	0.000	0.000	0.006	0.010	0.014	0.009	0.012	0.008
-1300	0.0	0.0	0.000	0.000	0.000	0.000	0.000	0.000	0.002	0.003	0.006	0.004	0.006	0.004
-1400	0.0	0.0	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.002	0.001	0.002	0.002
-1500	0.0	0.0	0.0	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.001	0.001	0.001
-1600	0.0	0.0	0.0	0.0	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
-1700	0.0	0.0	0.0	0.0	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
-1800	0.0	0.0	0.0	0.0	0.0	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
-1900	0.0	0.0	0.0	0.0	0.0	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
-2000	0.0	0.0	0.0	0.0	0.0	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

MAXIMUM CONCENTRATION IN THE ABOVE TABLE IS 0.519 PPM AND OCCURS AT (4500 , 0)

STACK	EFFECTIVE STACK HEIGHTS IN METRES AT ABOVE DOWNWIND DISTANCES												
1	137.	137.	137.	137.	137.	137.	137.	137.	123.	123.	123.	123.	123.	123.

CUMULATIVE POLLUTANT CONCENTRATION IN PPM AS A 0.50 HOUR AVERAGE AT A HEIGHT OF 0. M ABOVE THE GROUND

CROSSWIND DISTANCE (M)	DOWNWIND DISTANCE IN METERS													
	7500	8000	8500	9000	9500	10000	10500	11000	11500	12000	12500	13000	13500	14000
2000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.001
1900	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.001	0.001	0.001
1800	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.001	0.001	0.001	0.002	0.002
1700	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.001	0.001	0.001	0.002	0.002	0.003	0.003
1600	0.000	0.000	0.000	0.000	0.000	0.001	0.001	0.001	0.002	0.002	0.003	0.004	0.004	0.005
1500	0.000	0.000	0.000	0.001	0.001	0.001	0.002	0.003	0.003	0.004	0.005	0.006	0.007	0.008
1400	0.000	0.001	0.001	0.001	0.002	0.003	0.004	0.005	0.006	0.007	0.008	0.009	0.010	0.011
1300	0.001	0.001	0.002	0.003	0.004	0.005	0.006	0.008	0.009	0.010	0.012	0.013	0.015	0.016
1200	0.002	0.003	0.004	0.006	0.007	0.009	0.011	0.012	0.014	0.016	0.018	0.019	0.021	0.022
1100	0.005	0.006	0.008	0.010	0.012	0.015	0.017	0.019	0.021	0.023	0.025	0.027	0.029	0.030
1000	0.009	0.012	0.015	0.018	0.021	0.023	0.026	0.029	0.031	0.033	0.035	0.037	0.038	0.039
900	0.018	0.022	0.026	0.029	0.033	0.036	0.039	0.041	0.043	0.045	0.047	0.048	0.050	0.051
800	0.033	0.037	0.042	0.046	0.049	0.052	0.055	0.057	0.059	0.060	0.061	0.062	0.063	0.063
700	0.055	0.060	0.064	0.068	0.071	0.073	0.075	0.076	0.077	0.077	0.078	0.078	0.077	0.077
600	0.086	0.090	0.093	0.095	0.097	0.097	0.098	0.098	0.097	0.096	0.095	0.094	0.093	0.091
500	0.126	0.127	0.128	0.127	0.126	0.125	0.123	0.121	0.118	0.116	0.113	0.111	0.108	0.105
400	0.172	0.169	0.165	0.161	0.157	0.152	0.148	0.143	0.139	0.135	0.130	0.126	0.122	0.119
300	0.220	0.211	0.203	0.194	0.186	0.178	0.171	0.164	0.158	0.152	0.146	0.140	0.135	0.130
200	0.263	0.248	0.235	0.222	0.211	0.200	0.190	0.181	0.173	0.165	0.158	0.151	0.145	0.139
100	0.293	0.274	0.257	0.241	0.227	0.215	0.203	0.193	0.183	0.174	0.166	0.158	0.151	0.145
0	0.305	0.284	0.265	0.248	0.234	0.220	0.209	0.197	0.187	0.177	0.169	0.161	0.154	0.147
-100	0.295	0.277	0.259	0.243	0.229	0.216	0.204	0.194	0.184	0.175	0.167	0.159	0.152	0.146
-200	0.269	0.254	0.239	0.226	0.214	0.203	0.193	0.184	0.175	0.167	0.160	0.153	0.146	0.140
-300	0.228	0.218	0.209	0.200	0.191	0.183	0.175	0.168	0.161	0.154	0.148	0.142	0.137	0.132
-400	0.181	0.177	0.172	0.167	0.162	0.157	0.152	0.147	0.142	0.138	0.133	0.129	0.125	0.121
-500	0.134	0.134	0.134	0.133	0.131	0.129	0.127	0.125	0.122	0.119	0.116	0.113	0.111	0.108
-600	0.092	0.096	0.099	0.101	0.102	0.102	0.102	0.101	0.101	0.100	0.098	0.097	0.095	0.094
-700	0.060	0.065	0.069	0.072	0.075	0.077	0.078	0.080	0.080	0.081	0.081	0.080	0.080	0.079
-800	0.036	0.041	0.045	0.049	0.053	0.055	0.058	0.060	0.062	0.063	0.064	0.065	0.065	0.065
-900	0.020	0.024	0.028	0.032	0.035	0.038	0.041	0.044	0.046	0.048	0.049	0.051	0.052	0.053
-1000	0.011	0.013	0.016	0.020	0.022	0.025	0.028	0.031	0.033	0.035	0.037	0.039	0.040	0.041
-1100	0.005	0.007	0.009	0.011	0.014	0.016	0.018	0.021	0.023	0.025	0.027	0.028	0.030	0.032
-1200	0.002	0.003	0.005	0.005	0.008	0.010	0.012	0.013	0.015	0.017	0.019	0.020	0.022	0.023
-1300	0.001	0.002	0.002	0.003	0.004	0.006	0.007	0.008	0.010	0.011	0.013	0.014	0.016	0.017
-1400	0.000	0.001	0.001	0.002	0.002	0.003	0.004	0.005	0.006	0.007	0.008	0.010	0.011	0.012
-1500	0.000	0.000	0.000	0.001	0.001	0.002	0.002	0.003	0.004	0.004	0.005	0.006	0.007	0.008
-1600	0.000	0.000	0.000	0.000	0.001	0.001	0.001	0.002	0.002	0.003	0.003	0.004	0.005	0.006
-1700	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.001	0.001	0.002	0.002	0.003	0.003	0.004
-1800	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.001	0.001	0.002	0.002	0.002
-1900	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.001	0.001	0.001
-2000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.001	0.001

MAXIMUM CONCENTRATION IN THE ABOVE TABLE IS 0.305 PPM AND OCCURS AT (7500 , 0)

STACK	EFFECTIVE STACK HEIGHTS IN METRES AT ABOVE DOWNWIND DISTANCES													
1	123.	123.	123.	123.	123.	123.	123.	123.	123.	123.	123.	123.	123.	123.